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TECHNO-ECONOMIC VALUATION OF MOBILE COMMUNICATIONS SCENARIOS

Doctoral Dissertation

Jarmo Harno

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Faculty of Electronics, Telecommunications and Automation
Department of Communications and Networking

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Distributor:
Aalto University
School of Science and Technology
Department of Communications and Networking
P.O. Box 13000
FI-00076 Aalto
Tel. +358-9-470 25300
Fax +358-9-470 22474

jarmo.harno@gmail.com

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Opponent	Professor Erik Bohlin (Chalmers University of Technology, Sweden)
Supervisor	Professor Heikki Hämmäinen (Aalto University, School of Science and Technology)

Abstract

Valuation of large projects on new communications technologies is a challenging task. Major investments are required to spread out technology and services, the characteristics of which are still largely unknown. A balanced view is needed on capabilities of the technologies, market demand, and relevant value network actors and their economies. In this dissertation, comprehensive techno-economic modelling of these aspects will be introduced for valuation of selected business scenarios. The research framework is mobile data services and business architectures in the advent of new technologies, like UMTS (Universal Mobile Telecommunications System), WLAN (Wireless Local Area Network) and WiMAX (Worldwide Interoperability for Microwave Access). The techno-economic method in this context comprises the modelling of a large set of technology, market and other factors in relation to the business operations of the analysed market actors. The many uncertainties concerning future service innovations and market development set demands on scenario creation and parameter estimation. Traditional techno-economic investment project calculation is not enough.

This study gives devices for strategic decision making by analysing three different technology transitions: The modelling of Western-European incumbent operator business starting from the early 2000's indicated that the UMTS deployment should be started without delay to maximise the long-term profits from the acquired licenses, contrary to looking for short-term investment payoffs that was prevalent after the telecommunications downturn. Results also show that the emerging WLAN technology would not become a substitute for UMTS, but the public WLAN will complement the UMTS based business architecture. Modelling of the upcoming mobile WiMAX in comparison to UMTS path indicated that the mobile WiMAX cannot challenge the UMTS, as the latter one offers a better business case for the key actors. In the last transition, techno-economic delta analysis was used to quantify the benefits from the fixed-mobile convergence.

The main enhancements to the techno-economic method are first the extensive classification of advanced mobile services and related modelling of service diffusion, usage patterns, capacity requirements and revenues. The second contribution is to improve the analysis of service usage in relation to technology characteristics by integrating an end-user model that gives the demand and revenue potential of each service type, per user segment and utilised technology. A novelty is also the separation of network provisioning and service provisioning part of the business architecture into separate but interlinked models. The fourth contribution to the method is the application of real options method on large communications technology deployment projects, solving option modelling problems due to the complex dependencies of the project value on the investment timing. The introduced method starts from ordinary expected cash flow valuation, but adds to that the option value related to specific flexibility in the project.

Keywords Mobile services, business scenarios, value network, techno-economics, technology strategy, real option, telecommunications operator, 3G, UMTS, public WLAN, WiMAX, IMS

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Tiivistelmä

Suurten viestintäteknologiaprojektien taloudellinen arviointi on haastavaa. Vaaditaan suuria investointeja sellaisten teknologioiden ja palvelujen levittämiseen, joiden ominaispiirteet ovat vielä suurelta osin tuntemattomia. Tarvitaan tasapainoinen näkemys teknologioiden kelpoisuudesta, markkinatarpeesta, sekä arvoverkon toimijoista ja niiden taloudellisista resursseista. Tässä väitöskirjassa esitetään näiden asioiden kokonaisvaltainen teknis-taloudellinen mallintaminen valittujen liiketoimintaskenaarioiden arvon määrittämiseksi. Tutkimuksen puitteina ovat mobiilidatapalvelut ja liiketoiminta-arkkitehtuurit uusien teknologioiden, kuten UTMS (Universal Mobile Telecommunications System), WLAN (Wireless Local Area Network) ja WiMAX (Worldwide Interoperability for Microwave Access) vallatessa alaa. Tekno-ekonominen metodi sisältää suuren määrän teknologia- ja markkinatekijöiden mallintamista suhteessa analysoitavien toimijoiden liiketoimintaan. Tuleviin palveluinnovaatioihin ja markkinoiden kehitykseen liittyvät lukuisat epävarmuustekijät tekevät skenaarioiden luomisen ja parametrien arvioimisen haastavaksi. Perinteinen tekno-ekonominen laskenta ei riitä.

Tutkimus edesauttaa strategista päätöksentekoa monimutkaisissa projekteissa analysoimalla kolmea teknologiamuutosta: Länsieuroopan operaattoriliiketoiminnan mallintaminen 2000-luvun alusta lähtien osoitti, että UMTS verkkojen kehittäminen tulee aloittaa viipymättä, jotta pitkän tähtäyksen voitot hankituista lisensseistä saadaan maksimoitua - sen sijaan että etsittäisiin lyhyen tähtäimen tuottoja, mikä oli vallitseva ajattelutapa telealan laskusuhdanteessa. Tulokset osoittivat myös, että nouseva WLAN teknologia ei tule syrjäyttämään UMTS teknologiaa, vaan julkinen WLAN tulee täydentämään UMTS:än perustuvaa liiketoiminta-arkkitehtuuria. Vertailu WiMAX ja UMTS teknologioiden välillä osoiti ettei WiMAX voi uhata UMTS polkua, sillä jälkimmäinen tarjoaa paremmat liiketoimintaedellytykset avaintoimijoille. Viimeistä muutostilannetta tutkittaessa tekno-ekonomista delta-analyysia käytettiin osoittamaan telepalveluiden yhdistämisen (kiinteän verkon - ja mobiilipalvelujen konvergenssin) tuomat edut.

Tekno-ekonomisen menetelmän parannuksia ovat ensinnäkin edistyneiden mobiilipalveluiden kattava luokittelu, johon liittyy palvelujen leviämisen, käyttötapojen, kapasiteettivaatimusten ja tuottojen mallintaminen. Seuraava edistysaskel on palvelujen käytön analyysin kehittäminen lopppukäyttäjämallin avulla, jolla voidaan johtaa teknologioiden ominaisuuksia vertailemalla niihin perustuvien palveluiden kysyntä kussakin asiakassegmentissä. Uutta on myös verkko- ja palvelu liiketoiminnan erottaminen omiksi, mutta keskenään kytketyiksi malleksi. Neljäs metodin kehityskohde on reaalioptioden soveltaminen laajoihin viestintäteknologian projekteihin ratkaisemalla samalla optiomallinnuksen ongelmia, jotka johtuvat projektin arvon ja investoinnin ajoituksen välisistä monimutkaisista riippuvuusista. Esitetty menetelmä lähtee tavanomaisesta oletetun kassavirran laskennasta, mutta lisää tähän optioarvon, joka perustuu projektin joustavuuteen.

Asiasanat Mobiilipalvelut, liiketoimintaskenaariot, arvoverkko, tekno-ekonomia, teknologiastrategia, reaalioptio, teleoperaattori, 3G, UMTS, julkinen WLAN, WiMAX, IMS

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Preface

Since 2001, when I joined Nokia Research Center, I have been involved with techno-economic research of telecommunication networks and services, doing both internal projects and co-operation with European universities, operators and consultancies. The start fell to the time of the turning point from great hype for the Third Generation Mobile towards quite a depression in the industry. In the European co-operation projects, where much of the research that forms the basis for this thesis work were done, we had, however, an excellent spirit and motivation to look a bit further than most telecom people and to find out the light in the end of the tunnel of persistent deployment work and far-sighted investments. We were eager to do long days when meeting, and to have inspiring discussions even as having late dinners together, not to forget the counter-balancing tradition of jokes. I would like to take the opportunity here to present my gratitude to all the colleagues from universities of Athens, Aveiro and TKK; from Deutche Telecom, France Telecom, Swisscom, Telefonica and Telenor; Atlantide and JVH International.

I am especially grateful to my colleagues in Nokia, first of all to Ilari Welling, who hired me and have been a great support from the beginning as the leader in the big co-operation projects and a good friend in the numerous trips to the meetings in different parts of Europe. In addition to Ilari, I have had the privilege to have excellent colleagues in Kalevi Kilkki, Anssi Hoikkanen and Olli-Pekka Pohjola, with enthusiasm to develop new approaches in techno-economics and to share their knowledge and visions.

Although preparing an academic thesis had been in my mind from starting the techno-economic research, it is hard to say how long it would have taken to finalise, if I had not come to know Professor Heikki Hämmäinen, who became my supervisor. From the beginning of our discussions about the dissertation, the work got an enormous boost. When seeing my publications, Heikki said immediately that you have more than enough on the stack, so just start working on the summary and putting the thesis together. During this process, Heikki's deep vision in techno-economics and practical advices have been extremely important for me to get the bits and pieces to fit together to form a workable structure and have a decent outlook as a scientific piece of work. Many viewpoints burst into bloom only after the discussions and hints from Heikki.

I am indebted also to the scientific reviewers of the thesis, Professor Burkhard Stiller from University of Zürich and Professor Morten Falch from Aalborg University. Their comments encouraged me and pinpointed clear topics of improvement, and I am sure following them made the dissertation much better as an academic writing. I am grateful to William Martin for reviewing the language. After received such valuable supervision and advice, all faults and deficiencies remain my sole responsibility. My gratitude goes also to Professor Erik Bohlin from Chalmers University of Technology for devoting his time and expertise to act as an opponent of this dissertation. Thanks to Sanna Patana too, for her support in practical things relating to the dissertation process.

The composition and finalisation of the thesis was done beside my occupation in serving the telecom sector's IT needs with Wipro Technologies. I have received encouraging interest to the thesis from my colleagues Kari Pulkkinen and Esa Vitikainen and the inspiring discussions with them have opened new angles into the topics of the dissertation.

In addition to the colleagues, friends and family have been indispensable for me in being able to pursue this goal among all others. In the group of five couples we have kept connected since the fabulous university years, and besides, it seems that majority of us will now have the doctorate. I

am grateful for your support in all that life has brought into our way. I am celebrating the finishing of this leg also with you, my dear friends from the church. Thank you for the fellowship, common work and sharing of all things between heaven and earth. And you, our sailing mates, great to have you as companions in this journey too. Not to forget you, the families we are sharing the life within our close neighbourhood.

This occasion gives me the possibility also to give warm thanks to my parents Pirkko and George for their care from the beginning, giving the basis to make my own choices, supporting through all these years. Thanks also to my brothers and sister, with their spouses and children, and other relatives - you have been there since the beginnings, and the festive time get-togethers still are a privilege.

Finally, I am deeply thankful to you, my dear wife Hanna, for your wisdom and devotion in building our relationship – marriage courses have been a passion for both of us. We have gone through so many things together and have still much to go for, this dissertation being one step, now releasing time for others. Our daughters Pauliina and Petra, and our son Samu, you have been a delight in my life, and living with you and seeing you grow has been a tremendous privilege. Thank you all for your love. But in the end, surely, all our thanks go to our gracious God in Jesus Christ, whom we share in faith.

Espoo, 22 September 2010

Jarmo Harno

List of publications

Publication 1: Harno, J. (2004b). 3G Business Prospects - Analysis of Western European UMTS Markets. Proc. 1st International Symposium on Wireless Communication Systems (ISWCS). Mauritius, September 20-22, 5 pages.

Publication 2: Olsen, B. T., Katsianis, D., Dimitris D., Stordahl, K., Harno, J., Elnegaard, N. K., Welling, I., Loizillon, F., Monath T., Cadro P. (2006). Technoeconomic Evaluation of the Major Telecommunication Investment Options for European Players. *IEEE Network*, Vol. 20, no. 4, July/August, pp. 6-15.

Publication 3: Harno, J. (2009a). Techno-Economic Analysis of Beyond 3G Mobile Technology Alternatives. *info, Emerald Group Publishing*, Volume 11, Issue 3, pp. 45-63.

Publication 4: Harno, J., Katsianis, D., Smura, T., Eskedal, T., Venturin, R., Pohjola, O-P., Kumar, K. R. R., Varoutas, D. (2009a). Alternatives for mobile operators in the competitive 3G and beyond business. *Telecommunication Systems*, Volume 41, Issue2, pp. 77-95.

Publication 5: Harno, J., Bedo, J-S., Katsianis, D. (2005b). Analysis of 3G mobile technology rollout alternatives using real options methodology. Proc. NAEC2005, Italy, Oct 2005, 15 pages.

Publication 6: Harno, J., Kumar, K.R.R., Heikkinen, M., Kind, M., Monath, T., Von Hugo, D. (2009b). Service Offerings for Fixed-Mobile Convergence Scenario: An Integrated Operator Case. *International Journal of Business Data Communications and Networking (IJBDCN),* Volume 5, Issue 3, pp. 1-16.

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2.5G	2G Systems + Advanced Data Services (e.g. GPRS)
3G	Third Generation Mobile Systems (e.g. UMTS)
3GPP	3rd Generation Partnership Project (collaboration standards body)
ARPU	Average Revenue Per User
AS	Application Server
ASP	Application Service Provider
BGCF	Breakout Gateway Control Function
BHSA	Busy Hour Service Attempt
BMG	BRAIN Mobility Gateway
BRAIN	Broadband Access for IP Based Networks (IST-1999-10050)
BS/BTS	Base Station (UMTS/GSM)
BSC	Base Station Controller (GSM)
BSS	Base Station Subsystem / Business Support System
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CCCF	Call Continuity Control Function
CDMA	Code Division Multiple Access
CDMA450	CDMA for 450 MHz frequency band
CPE	Customer Premises Equipment
CRM	Customer Resource Management
CS	Circuit Switched
CSCF	Call Session Control Function
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DVB-H	Digital Video Broadcasting – Handheld (technical specification for bringing broadcast services to handheld receivers, ETSI standard)
EDGE	Enhanced Data Rates For Global Evolution
EIR	Equipment Identity Register
ERX	Edge Router Switch
ETSI	European Telecommunications Standards Institute
EU	European Union
FDD	Frequency Division Duplex
GGSN	Gateway GPRS Support Node
GMSC	Gateway Mobile Switching Center
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile communications
HSDPA	High-Speed Downlink Packet Access
HSPA	High-Speed Packet Access
HSS	Home Subscriber Server
I-CSCF	Interrogating Call Session Control Function
IBCF	Interconnect Border Control Function
IEEE	The Institute of Electrical and Electronics Engineers
IMS	IP Multimedia Subsystem
IP	Internet Protocol
IRR	Internal Rate of Return

ISDN	Integrated Services Digital Network
IST	Information Society Technologies
ITU	International Telecommunications Union
kbps	kilobits per second
LAN	Local Area Network
LBS	Location-based Service
LRU	Line Replacement Unit
LTE	3GPP Standardised Long-Term Evolution of UMTS (WCDMA)
MAN	Metropolitan Area Network
ME	Mobile Equipment
MGCF	Media Gateway Control Function
MGW	Media Gateway
MIMO	Multiple Input Multiple Output (Antenna)
MMS	Multimedia Messaging Service
MNO	Mobile Network Operator
Mobile WiMAX	WiMAX with mobility support (IEEE 802.16e)
MRFC	Multimedia Resource Function Controller
MRFP	Multimedia Resource Function Processor
MSC	Mobile Switching Center
MVNO	Mobile Virtual Network Operator
NeDS	Network Domain Selection
NGN	Next Generation Networks
NO	Network Operator
Node B	UMTS Base Station and Base Station Node
NPV	Net Present Value
OA&M	Operation, Administration and Maintenance
OPEX	Operational Expenditure
OFDM	Orthogonal Frequency Division Multiplex
OMC	Operation and Maintenance Center
OSS	Operations Support System
P-CSCF	Proxy Call Session Control Function
PCM	Pulse-Code Modulation (in digital telephone lines)
PCRF	Policy and Charging Rule Function
PLMN	Public Land Mobile Network
PS	Packet Switched
PSTN	Public Switched Telephone Network
QoS	Quality of Service
RMP	Relative Market Power
RNC	Radio Network Controller (UMTS)
ROI	Return of Investment
S-CSCF	Serving Call Session Control Function
SGSN	Serving GPRS Support Node
SIM	Subscriber Identity Module
SMS	Short Message Service
SO	Service Operator
SP	Service Provider
TCP	Transport Control Protocol
TRx	Radio Transceiver
TrGW	Translation Gateway
UE	User Equipment

UMTS	Universal Mobile Telecommunications System (as defined by 3GPP)
USIM	UMTS SIM
VASP	Value Added Service Provider
VCC	Voice Call Continuity
VLR	Visitor Location Register
WAN	Wide Area Network
WCDMA	Wideband Code Division Multiple Access (3G radio technology by 3GPP, relates to UMTS)
WiMAX	Worldwide Interoperability for Microwave Access (IEEE 802.16)
WLAN	Wireless Local Area Network
VoIP	Voice over IP
WWW	World Wide Web

1. INTRODUCTION

1.1 Motivation

Valuation of advanced mobile communications projects at the early phase of the technology development is vital for the business actors, as the required investment costs are high and the decisions made have a lasting impact. The aim of this doctoral dissertation is to develop and apply techno-economic methods to support the challenging strategy formation in the rapidly developing technology and market environment of mobile communications. Solid methods are needed to evaluate and compare the different technology scenarios to select the right business architecture and technology path.

The value of the techno-economic approach should be demonstrated by solving the actual problems faced by the business actors in the advent of several new technologies, services and business possibilities. The goal has been in all case studies to increase the understanding and measurability of the business prospects by building up a comprehensive model of the business case, where the revenues are explicitly linked to the investment plan and potential demand development, not forgetting the incurred operational costs.

The techno-economic approach was more straightforward for earlier fixed network projects where the problem used to be more cost driven (Ims 1998; Monath et al. 2003; Olsen et al. 1996), but for advanced mobile technologies the revenue side is much more demanding, as the service realisation as well as their demand is to large extent unknown. In spite of this and actually because of this, adequate techno-economic research is needed to help the market actors, as well as the regulatory authorities, in their strategic decision making. By explicitly modelling all the parameters, being uncertain or deterministic, it is possible to discover the dynamics of the case by model simulation and parameter adjusting, as there are certain justifiable boundary conditions too - like consumer disposable money.

Contrary to studies where only one technology or service is investigated at a time, our approach does not lead so easily into the pitfall of overestimating the potential of the particular service or technology under investigation. The total economic resources on the provider side as well as on the purchaser side are limited, which should be taken into account. Also market research based only on user questionnaires, and other such kind of measures, can lead astray, as the business actors' interests and actions in the competitive situation are not considered.

1.2 Research question

The research question in this thesis is:

- Can the techno-economic method provide quantitative means to valuate advanced mobile communications business prospects and compare different technology alternatives, and what improvements to this method are possibly needed to achieve this?

This question is approached within three technology frameworks: UMTS/WLAN, UMTS/WiMAX and fixed/mobile convergence through UMTS IMS. In relation to each technology study, also some steps are taken in the techno-economic method development, as well as in the separate study on real options applicability.

Valuation of UMTS and competing technology deployments

In the valuation of advanced mobile technology projects, the challenge has been in the vague foresight of the service demand, technical development and market stakeholder actions. Our studies aim to demonstrate that the comprehensive techno-economic analysis has predictive power in estimating the profitability of different technology deployment alternatives for the modelled business actors, and more generally in predicting the success and market position of the competing technologies.

This study starts by valuating the UMTS deployment in Western Europe, aiming to verify if it is economically feasible to invest in UMTS networks and service development instead of sticking to less advanced technologies. What would be the cost to build the UMTS network and other 3G service infrastructure? What would be the revenue potential from the services during that period and what would be the realistic schedule for the deployment to make a feasible business case? What will be the effect of delay on the business case, and can measures like infrastructure sharing have an important role?

A related problem in this context is the role and business value of the public WLAN technology, which was seen by many experts to supersede UTMS technology, as providing a more advantageous solution for high data speeds. Should it be reckoned as a competitor to UMTS, so that the operator could build its mobile data business solely upon it, or could it provide a complementary technology, and if so, what would be its value for the operator?

As OFDM (Orthogonal Frequency Division Multiplex) based technologies became the new challengers to UMTS, and later especially the mobile WiMAX technology, the goal in this research was to analyse the technology competition. The study aims to provide results for the investigated business actors to help in the strategic selection of the most profitable technology path. Economic results of UMTS technology, with the evolutionary path through HSPA (High-Speed Packet Access) towards LTE (Long-Term Evolution of UMTS), should be compared against the potential of the mobile WiMAX technology evolution. Also the intermediate technologies, like EDGE (Enhanced Data Rates for Global Evolution) in GSM family, have to be taken into account in this modelling.

In addition to an operator owning its mobile network (MNO), the study includes also problem settings relating to Mobile Virtual Network Operators (MVNOs). What are the business prospects for the MVNO, and what additional possibilities does it give for the Network operator in the 3G context?

The last phase concentrates on the feasibility of the fixed-mobile convergence for the integrated operators (having both fixed and mobile business) as a continuum for the UMTS and its IP Mobility System (IMS). The study tries to track through comprehensive modelling of this business transformation, if the benefits of converged service provisioning would be greater than the losses. It is not only a matter of technology, but also a large change process in the organisation, which has to be taken into account. The research target is to quantitatively analyse the positive and negative economic effects for the integrated operator, if selecting the convergence path.

Methods development

Along the journey to cope with the above problems the target has been to develop methods to model the advanced communications business. The new services require future looking analysis to provide estimates for their revenue generating potential and, on the other hand, for the generated usage and traffic patterns leading to their cost impact.

The technology comparison related to provisioning of these services requires means to model the differences in user experience through each technology and the related effect in usage and thus revenue. Since the new services are no longer simple operator provided utilities, like voice call service or SMS, the method has to be developed towards the analysis of the complete end-to-end value chain of the services by separating the network and service provisioning actors and integrating the end-users and their behaviour into the techno-economic modelling. In addition to business forecasts based on service modelling and diffusion, the end-user benefit model is needed to quantify the usage differences between different technologies.

As the market development is largely unknown in the beginning, methods are needed to analyse the risks and sensitivity related to the baseline results, and to be able to integrate into the economic calculations the value of the possibility to make some of the investment decisions later, when there is more information available.

1.3 Research method

The research method aims for a holistic quantitative modelling of the telecommunications operator business with a balanced investigation of technology and market parameters at a feasible granularity, leading to cash flow analysis of all costs and revenues and derived economic key figures. Instead of trying to evaluate a technology as such or the market potential per se, the relationship between them is emphasised, basing the modelling upon scenarios about the actions taken by the stakeholders in the course of the market development.

Network capacity and coverage, as well as device and service characteristic, are modelled with detailed parameters for the analysed technologies, taking into account the country specific demographic and geographic data. Potential user penetrations of each technology are based on market forecasts, for which a logistic diffusion model is utilised. In the first part of the studies, the service usage and the generated traffic figures are based on analysis of future services, but in the latter ones, also the end-user, as a crucial actor in the changing technology environment, is modelled. The usage differences of the technologies are based on end-user benefit modelling. Different investment plans can be compared by simulation runs with the model, counting all the relating service revenues, investments and operational costs, to obtain the optimal deployment plan.

In addition to comprehensive cash flow analyses to gain the economic key figures, the uncertainty of the assumptions are tackled by risk and sensitivity analyses, and the flexibility in the investment plan by real options analysis, to improve the usefulness of the results for strategic decisions.

1.4 Background of the research

Publications 1 and 2 in this thesis relate to the project TONIC (2001-2002), in the European Union’s IST programme, investigating the third generation mobile network prospects in Western

Europe. The hype surrounding 3G was changing to recession in the industry during this project. Even the whole feasibility of building UMTS networks and providing handsets was questioned in 2002. Most operators were hesitating to launch UMTS, as they were looking for short term profits. At the same time, most analysts changed their position towards suggesting long delays in UMTS adoption. The aim of the techno-economic analyses was to investigate the profitability of the UMTS network and services provisioning in the long run (2003-2011), within the context of a high market share operator that has acquired a 3G license in a Western-European country. Also the role of WLAN in the context of a large incumbent operator was studied. The author of the thesis was the main single contributor for the UMTS/WLAN case modelling over the TONIC project life time.

Publications 3 and 4 are based on the European CELTIC framework project ECOSYS (2003-2007) study setting, where the OFDM based technologies, first Flash OFDM and then mobile WiMAX were identified as challengers to UMTS in providing mobile data services. In addition to questions relating to technical parameters, the maturing outlooks of the technologies had to be taken into account, combined with market actor positions - all before the actual commercial deployments. The author of the thesis was the leader of the Mobile Work Package in the ECOSYS project and modelled the UMTS/WiMAX comparison case study.

Publication 5 and two other cited real option articles by the author, improve the valuation to take into account the possibility of postponing the start of the rollout to certain areas, or not to deploy the technology at all in certain areas, or wait and select another competing technology – if the conditions develop in another direction than assumed in the beginning. Without this improvement, the valuation gives inaccurate results, if there is real flexibility in the project realisation. But one should be careful not to apply the options calculation too straightforwardly. As a lot of differences exist between the economics of communications technology projects and stock options, the option value may easily be exaggerated.

Publication 6 investigates the cost structure changes and market possibilities relating to the fixed-mobile convergence that was studied also in the ECOSYS project. This development is taking place in Europe among the major incumbent integrated operators having historically the separate fixed and mobile communications arms, but the pace of this change has been slow and there seems to be uncertainty about the related threats and benefits.

1.5 Structure of the dissertation

The first chapter gives the introduction, objective and background for the dissertation. Chapter 2 continues by introducing the mobile communications business architectures and technology architectures, and their development. Chapter 3 describes the techno-economic modelling methods utilised in the business case analyses.

Chapter 4 goes into the actual studies and acquired results, starting with the first techno-economic modelling approach, which is based on early forecasts of UMTS service provisioning and usage, combined with the public WLAN offering. The second subsection presents the techno-economic model for comparison between UMTS and WiMAX business cases. The third subsection enhances the previous cash-flow models with real option analysis, which brings into the economic calculation the value of flexibility in decision making. The last subsection presents a fixed-mobile convergence case study, estimating the potential increase in profitability, if the fixed and mobile services are fully integrated.

The last chapters close the dissertation with conclusions and suggestions for further study. Original Publications are attached to the end of the dissertation.

2. RESEARCH FRAMEWORK

2.1 Business architectures

In the techno-economic study setting, technology as such cannot drive the business case. To analyse a mobile business case in the B3G era, several domains are needed to be combined, all containing new challenges:

- Technologies
- Markets
- Services
- Business architectures

The 3G and beyond mobile business architecture consists of the value networks of business actors, upon which versatile technologies are mapped to generate the services in each market situation. The monolithic, operator infrastructure investments centric, approach of telecommunications techno-economics (e.g. Ims 1998; Katsianis et al. 2001; Monath et al. 2003), that has preceded these studies, is no longer adequate in the situation of converging communications, media, and IT industries, where different partnering schemes are needed for service integration. New market and service related parameters and the actors' own competitive position and resources should be analysed as putting increased emphasis on the structure of the operational costs.

Getting the business architecture for a techno-economic case analysis requires cutting the service provisioning value chain or network into the possible actors, roles and relationships and defining the value-adding activities and revenue sharing models. These should imply the technology architecture, its components and interfaces leading to the investments and operational costs, and the end-service pricing issues. The related technology architectures are handled in the next chapter.

Parameters relating to a specific market have to be defined for the actual business case:

- country demographics
- general market parameters
- own starting position and resources
- other business actors, their interests and strengths
- bargaining power in revenue sharing and procurements

In Publication 1 and Publication 2 the interest was primarily on 3G service launch in Western Europe. The key actors were the large incumbent operators, who had made significant investments in 3G licenses in the largest Western European countries. Incumbents typically own both the network and service provisioning facilities. They were also winners in the "beauty contest" auctions in most of the lower population (e.g. Nordic) countries. The new challengers were not seen as so important actors in this context, but also challenger cases, starting without their own 2G infrastructure, are modelled.

Studied business cases include also the MVNO case (Publication 2 and Publication 4), where the modelled actor does not have its own radio network at all, but rents it to provide the services for its subscribers. This case has been combined with the Mobile Network Operator (MNO) case to calculate the effect from the MNO business case point of view. Although the MVNOs have a vulnerable position, they can act as boosters in the communications service provisioning.

In Publication 3 and Publication 4, that introduce the competitive OFDM or WiMAX radio technologies, the need to separate fully the Network operator and Service operator models was identified. Having this interface as explicit makes it possible to analyse the dynamics between these business actors relating to different technologies and competitive situations. The separation of those market roles in the bookkeeping has been also required by the authorities in many countries for competition supervision reasons.

In this thesis the concept of business architecture is utilised instead of business model, although the latter one is more commonly used term in current literature. What is meant with business model, however, is not self evident even in the economic literature. Within the field, business modelling is still a young discipline (Osterwalder et al., 2005). It could be even argued that there is no comprehensive definition for business modelling at all. Commonly technology-oriented and business-oriented people tend to use the term “business model” differently. In the literature there are several approaches to business modelling, a short summary that is followed below can be found in Harno (2009).

In McKinsey & Company (1999) a business model defines how a company produces a product or a service and how it is delivered to the customer. It arises from the definitions of the activities of a company and their interrelationships. Timmers (1998) emphasises the architectural description of the product, service and information flows, including the various business actors, their roles, potential benefits and sources of revenues. Slywotzky (1996), on the other hand, has a more functional definition, consisting of how a company selects its customers, defines and differentiates its offerings, defines the tasks it will take itself and those it will outsource; how it configures its resources, how it goes to market, creates utility for customers and earns a profit from that activity. For Afuah & Tucci (2000), a business model combines potential environmental factors and a firm’s capabilities, providing a sustainable recipe to offer competitive products or services with relevant revenue logic.

A more recent definition by Weill & Vitale (2002) emphasises the partnership dimension of the roles and relationships among a firm’s consumers, customers, allies, and suppliers identifying the major flows of product, information, and money, and the major benefits to the participants. Finally Osterwalder & Pigneur & Tucci (2005) defines business model as a description of the value a company offers to one or several segments of customers and of the architecture of the firm and its network of partners for creating, marketing and delivering this value, to generate profitable and sustainable revenue streams.

The business architecture term, on the other hand, was originally used in connection with the enterprise strategy and organisation, commonly linked closely to the dilemma between the business requirements, processes, organisation and IT structure. The Business Architecture Working Group (2009) defines it as "A blueprint of the enterprise that provides a common understanding of the organisation and is used to align strategic objectives and tactical demands." In this thesis, however, business architecture is not used to describe the enterprise internal structure, but for the full value network comprising of several partnering companies and even participating consumers. The winning architecture would be the one which provides the best service through the best functioning supply network with best products adaptable to the emerging usage scenarios. There should exist a mapping between the end-to-end business architecture and technology architecture, and it should have openness for an evolution path to serve a variety of still undefined needs.

Another concept to combine the business models, value networks and technology architectures, used widely in recent discussion, is business ecosystem or communications ecosystem. Early detectors of the shift to the new economy were Shapiro and Varian (1999) who note that traditional rules of competitive strategy focus on competitors, suppliers, and customers, but in the information economy, companies selling complementary components, or “complementors”, are equally important. An actor in the ecosystem cannot compete successfully, if it provisioning (service or product) is not compatible with the rest of the system. Iansiti & Levien (2004) state that stand-alone strategies do not work when success depends on the collective health of the organizations influencing the creation and delivery of the product. Right strategy requires understanding the ecosystem and organization's role in it. Kilkki (2008), emphasize also the human behavioural aspects in the development of the communications ecosystem.

Business architecture can be used to describe the evolution of a whole value network of several actors, whereas a company’s business model focuses on its own interests in the value network. In this thesis, the term “business plan” is used for a set of strategic decisions of a particular company fitting into a wider business architecture. It may relate, for example, to a company’s own technology rollout schedules. Value network is defined by Bitran et al. (2003) as a cluster of actors that collaborate to deliver value to the end consumer and each actor takes some responsibility for the success or failure of the network. The emphasis is shifting from single-firm revenue generation towards multi-firm control and interface issues (Gawer & Cusumano, 2002). The guiding question of a business model becoming ‘‘who controls the value network and the overall system design’’ just as much as ‘‘is substantial value being produced by this model (or not)’’. Ballon (2007) argues that it is precisely the alignment of control and value parameters that is of most relevance to business modelling.

The service-oriented thinking has been the major trend in information technology during the first decade of 2000 and has been adopted to the communications industry especially through the TeleManagement (TM) Forum (2009). The TM Forum Solution Frameworks (NGOSS) can be viewed as master plans to guide towards service-orientation, by implementation of the processes by reusable Business Services. As the end-to-end perspective is emphasised with the need for new partnering agreements in the current development, modelling from the whole industry perspective is needed to cover the emerging value networks and usage scenarios. It has been found out in case studies relating to, for instance, interactive TV, that the technology-oriented enterprises might have difficulties in discovering the service concepts and usage scenarios that can be conceived by the content and service providers which are closer to the end-user (Konrad 2008). For this reason, the architecture considerations should not be based only on the technological dimension, but also reflect the service-oriented end-to-end business architecture, comprising fruitful partnering schemes.

The challenge for the business actors (especially the telecommunications operators) is in finding or creating the right business architectures for service provisioning and money flows to build up a profitable business. In many cases the “weakest link”, or least motivated actor, in the value chain can ruin a business case for all actors; like in the case of the unavailability of the right kind of devices needed for the service. Research results indicate that it is easier for the companies to discern the benefits of the technology development for the products and services, than to see the changes needed in the strategic business approach (Sainio 2005). The ability to create mobile data business architecture of virtuous circle with growing externalities is very much a result of the techno-economic combination of technical features with the right provisioning and pricing model

(Saarikoski 2006). Co-operation and partnering are needed on and between several layers of the business ecosystem to create a flourishing service business. A study by Bohlin E. et al. (2003) confirms that one of the key factors that explain why i-mode was a success in the Japanese mobile market was that the leading operator NTT DoCoMo created a viable business ecosystem where all actors, including operators, content providers, terminal manufacturers, portal/search engine providers and distributors cooperated and had possibilities to run a profitable business

All in all, the challenge is to identify the elements, roles and relationships that describe the value network and the business of a company with the right focus and depth to make the estimation of the future development possible. A practical model needs to compile the selected technology, market and business structure inputs into the required economic outputs.

In techno-economic modelling, the handling of business architectures, earning logics and cost modelling (of both operational and capital expenditures) of the business actors has to be combined with more fuzzy market demand and spending forecasts of right granularity to gain balanced results. Most of the technology/market research of communications systems and services are not public but done by commercial analysts or inside the companies. However, public funded research projects have produced some techno-economic analyses that combine economics, market forecasts and business strategy aspects with a comprehensive technology architecture modelling (Ims 1998; Katsianis et al. 2001; Monath et al. 2003; Harno et al. 2007).

Business architecture modelling

Although published quantitative models are rare, there are studies for explicit mobile communications value network decomposition. Sabat (2002) still uses only the term “value chain” and differentiates two broad segments of “Content-related services and applications” and “Network infrastructure and access devices”. Content-related services and applications are further divided into “Content providers” and “Mobile wireless content enablers”. The Network infrastructure and access devices segment is divided into “Network infrastructure providers” and “User interface or access device vendors”. Li & Whalley (2002) introduces the interwoven value network and value chain in the new telecommunications industry with “myriad of network relationships”. Steinbock (2003) states that through the pre-cellular phase and the 1G era, a single network operator, typically the national PTT, *was* the wireless value system in most developed country markets. For the 3G era he distinguishes a system composed of seven constituents: Manufacturing Contractors, Equipment Manufacturers, Platforms, Chips, Application Software, Content/Aggregation and Location Specific Systems. Rülke et al. (2003) divide the wireless value network into elements of Content and application providers, Portal and access providers, Wireless network operators, Support services, Delivery platforms and Applications.

Peppard & Rylander (2006) divide their value network into 1) Customer relationship business, 2) Service and content innovation and commercialisation businesses and 3) Infrastructure management business, providing network access and mediating capability. In contrast to the value chain logic, these functions are performed simultaneously rather than sequentially. They notice also that “Currently, most mobile operators, particularly the main players, manage these functions under the same organisational roof.” Due to that, the ability to offer innovative products to customers may be limited by the underlying technological characteristics of the core network or by the need to avoid cannibalising the organisation’s own sales in other divisions. Finally Pagani & Fine (2008) separates “Handheld Device Manufacturer”, “Wireless Network Operator”, “Portals and Access

Provider", "Application Developer", "Content Provider" and "Content Aggregator", which divide even into sub-constituents.

An extensive division of value network elements of communications business architectures was introduced by ECOSYS project (ECOSYS Deliverable 03, 2004). It covers widely the elements of the referred literature and some additional items. It has been selected as a basis for the following analysis, which somewhat modifies the definitions of the roles and relationships. The focus is on the generic communications value network, so that the internal enterprise business processes are not involved.

Definitions

The definition for business architecture adopted here is based on the definitions provided by Chesbrough & Rosenbloom (2002) and Timmers (1998) stated as follows: Business architecture consists of service, money and information flows, including descriptions of various business actors, their roles and relationships, their relative position within a value network and description of their cost structure and sources of revenue. The end-to-end business architecture should be mappable to the end-to-end technology architecture and they should be able to evolve together to provide for future service needs.

Value network is defined as a network of relationships that generates economic and other types of value through dynamic exchanges between two or more participating actors.

The other key concepts are defined as follows:

- Actor: Participating entities in the business architecture. It can either be 1) a business entity that provides services or 2) customer that consumes services.
- Role: Functionality of an actor in a business architecture. An actor can take one or more different roles.
- Relationship: Interaction between two roles/actors in the system. Business-wise this interaction can consist of contracts, services, monetary flow, etc. The interactions are implemented through the technology architecture and may be imposed by it.
- Revenue model: A revenue model describes the revenue streams available for an actor in the business architecture. Some examples of revenue models are subscription and transaction fee based models.
- Cost model: A cost model describes respectively the cost drivers of an actor in the business architecture. An example of cost model is how the needed network capacity is procured.

The shapes that the above key concepts take in the business architecture are influenced by and interacting with the chosen technology architecture path.

Roles

Figure 1 illustrates roles that exist in the communications ecosystem.

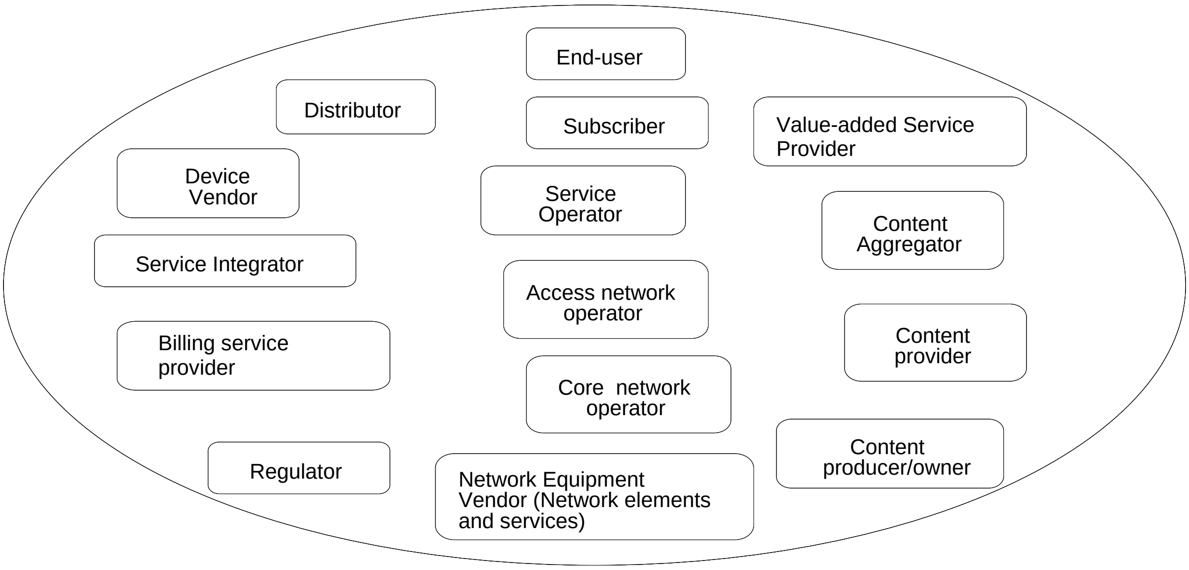


Figure 1: Roles in communications ecosystem (modified from ECOSYS Deliverable 3, 2004)

Table 1 describes the roles illustrated in Figure 1.

Table 1: Role definitions

Role	Description
End-user	An entity taking up this role is the ultimate consumer of services and content provided in the communications ecosystem.
Subscriber	An entity taking up this role pays for the services and content provided in the communications ecosystem and has a direct relationship with the provider. However, this entity may not necessarily be the end-user of these services and content. A subscriber can be classified as: 1) Post-paid or pre-paid (based on mode of payment), 2) Consumer or business (based on type of entity)
Service operator	An entity taking up this role provides subscriptions for communication and distribution services over communications networks (fixed-line, mobile, terrestrial wireless, satellite). A Service operator does not own the networks. It enters into service level agreements (SLAs) with access and core network operators for network capacity. Other major responsibilities of this role include: 1) management of subscriber profiles, subscriber acquisition and retention 2) providing security services 3) charging and billing the subscribers for service usage. The Service operator may resell its network capacity to third parties such as content aggregators. This role may be taken by an MVNO.
Content aggregator	An entity taking up this role acts as an intermediary between Content providers and End-users or Service operators for offering a portfolio of content (such as applications supporting e.g. social networking, games, music, TV programming or just ringtones and logos). It takes the content produced by Content providers, and converts it into a suitable format depending on the context (device capabilities, location, personal indications/preferences, etc.) and may rely on the VAS providers. It may offer several types of content at a single stop (e.g. a content portal) combining music, videos, books, etc. Content and applications may also be developed and provided for free, based on Open Source and/or revenues generated from advertisements, or increased usage value for the end-user, thus adding value to the subscription or device.
Content provider	An entity taking up this role publishes and sells content or applications developed itself or by other content producers. Other activities include marketing the content, conducting market research, etc. Sega, a game publisher is an example of a content provider.
Content producer/owner	An entity (business or individual) that takes up this role would develop and maintain content or applications such as music, games, etc. It may own the content or act as developer for an owner.
Value-added service provider (VASP)	An entity taking up this role provides services that are complementary in nature or add value to the basic set of services provided by a Service operator. Examples of such services include location-based services and presence.
Billing service provider	An entity taking up this role provides billing services to the Service operator, VASP or content aggregators. This role may also act as a financial intermediary (or clearing house) between two or more operators or providers. Usually the Service operators/Core network operators play this role, and can even bill non-communications services, like small purchases. But other actors like credit card companies and banks could take care of the billing.

Device distributor	An entity taking up this role acts as the retailer for end-user device and related appliances.
Device vendor	An entity taking up this role provides customer equipment, such as desktop computers or mobile devices used by the end-users. It may also provide auxiliary software and hardware such as operating systems and batteries essential for the proper functioning of the device.
Access network operator	An entity taking up this role owns and administrates the access networks such as DSL, mobile, cable, broadcasting network, and provides transmission or bearer services to the Service operator. It sells access network capacity to Service operator enabling it to reach its subscribers.
Core network operator	An entity with this role owns and administrates the core network elements such as switches, routers, gateways and management units, offering core network capacity to the Service operator.
Transport network operator	An entity taking up this role owns and administrates the transport networks such as optical backbone networks and provides transport services to the Core network operator.
Network equipment vendor	An entity taking up this role primarily manufactures either by themselves or through original equipment manufacturers (OEMs) network elements and related services and distributes them to network operators (both access and core) as well as to Service operators.
Regulator	Regulator’s primary role is to maximise social welfare by suggesting and enforcing rules for sustaining a competitive market and technological environment. Regulator’s aim is to prohibit monopoly, misuse of dominant market power, and vertical integration where part of the value chain is subsidised to block competition. This role is important for formation of value networks.
Service integrator	An entity taking up this role provides service and delivery platform functionality that enables roles without extensive knowledge of the underlying communications system to offer services and application access to subscribers. Some examples of these functionalities include Parlay/OSA Gateway that provides APIs for charging and billing service, QoS etc. Service integrator role can be also to provide systems integration to develop the operator BSS and OSS functionality to cope with the new services.

Relationships

Understanding the relationships that exist among the business entities taking up one or more roles is crucial for designing business architectures. The user-provider relationships between the roles described above are comprised into the reference model illustrated in Figure 2 below. The directions of arrows indicate the value flow. The business relationship interfaces in Figure 2 are described in Table 2.

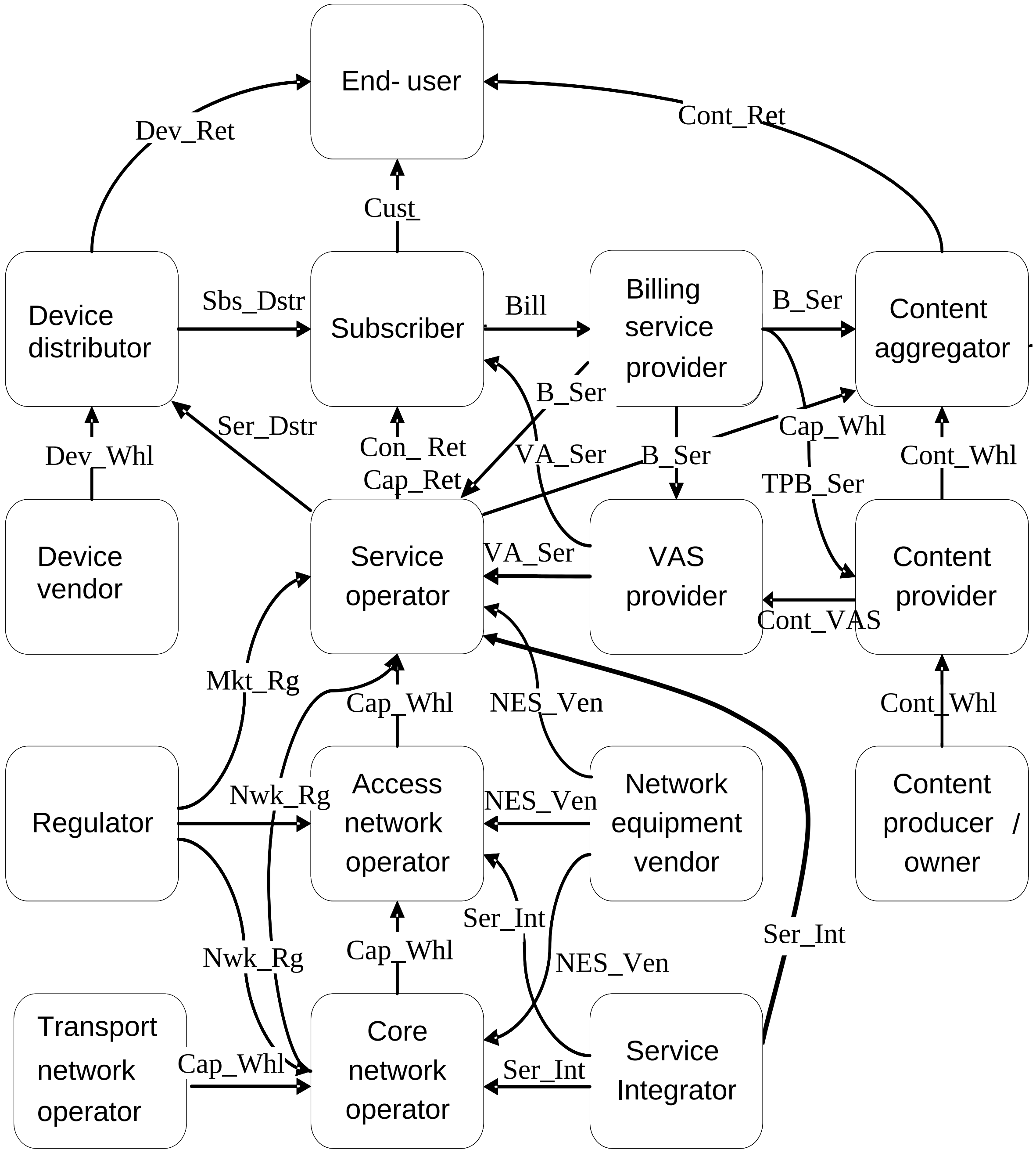


Figure 2: Roles and Relationships reference model (modified from ECOSYS Deliverable 3, 2004)

Table 2: Relationship interface definitions

Interface	Description
Cust_	This interface represents the relationship between the End-user and the Subscriber roles. Subscription may also have been made by an actor other than the end-user, e.g. by an employer or parents.
Dev_Ret	This interface represents the retail relationship developed between the Device distributor and End-user roles for the distribution of devices and related appliances.
Dev_Whl	This interface represents the relationship for the wholesale distribution of devices and related appliances. This relationship exists between the Device vendor and Device distributor.
Ser_Dstr	This interface represents the relationship developed between Service operator and distributor roles. Service operator may subsidise devices and/or pay commission to the distributor who facilitates the subscription between the Service operator and the device purchaser.
Sbs_Dstr	This interface represents the relationship developed between the Subscriber and Device distributor roles. The distributor may market the subscription with a Service operator in connection to the sold devices.
Con_Ret	This interface represents the relationship in making and fulfilling the retail contracts (subscriptions) for communications service packages, for voice, messaging, data transfer, media channels, etc. This relationship exists between Service operator and Subscriber.
Cap_Ret	This interface represents the relationship for the retail provisioning of transmission or communication service capacity, or transactions. This relationship exists between the Service operator and Subscriber.
Cont_Ret	This interface represents the relationship for the retail provisioning of content or applications. This relationship exists between: 1) Content aggregator and End-user/Subscriber 2) Content provider and End-user.
Cont_Whl	This interface represents the relationship for the wholesale provisioning of content. This relationship exists between: 1) Content aggregator and Service operator 2) Content provider and Service operator 3) Content provider and Content aggregator 4) Content producer and Content provider. (The first two relate to the case, where the Content aggregator/provider is a subcontractor of the Service operator; arrows are not depicted in Figure 1).
Cont_VAS	This interface represents the relationship between roles for the VAS provisioning and VAS related content and application provisioning, e.g. provisioning electronic maps, location related information and navigation SW, or TV-programming.
Cap_Whl	This interface represents the relationship between roles for the wholesale provisioning of network capability and capacity services, including accessibility, connectivity, security, QoS and charging. This relationship exists between: 1) Access network operator and Service operator 2) Core network operator and Access network operator 3) Core network operator and Service operator.
Bill	This interface represents the relationship between the Subscriber and the Billing service provider roles. Billing may be based on subscription or per transaction, service, content or capacity usage.
B_Ser	This interface represents the relationship between roles for the provisioning of billing services. This relationship exists between a billing provider and the following roles: 1) Service operator 2) VASP 3) Content aggregator/provider.

Mkt_Rg	This interface represents the relationship developed between the regulator and Service operator roles for the implementation of market regulations in order to provide market fairness. Pricing regulation is one example of such market regulation.
Nwk_Rg	This interface represents the relationship that exists between regulator and the Network operator roles (both access and core) for the implementation of network regulations such as mobile spectrum distribution, wholesale pricing and interconnection.
Ser_Int	This interface represents the relationship that exists between the Service integrator and operator roles for the implementation of service platforms and support systems. Integration services can be provided also for the Content aggregator, Billing service provider and VAS service provider roles.
VA_Ser	This interface represents the relationship between a Value-added service provider and the role of: 1) Service operator 2) (direct) Subscriber.
NES_Ven	This interface represents Network equipment vendor's relationship with the following roles: 1) Core network operator 2) Access network operator 3) Service operator.

Business architectures in the case studies

The scenarios in this thesis are based on the assumption of a telecommunications operators' active and major role in the service provisioning, although the later market development indicates that the influence of the equipment vendors is increasing on the mobile communications service provisioning value network. Nevertheless, the emphasis of the study has shifted towards the service provisioning economics, related operational costs and end-user experience.

The mobile communications business architecture has traditionally been based on "vertical bundling". This is also known as vertical integration, where one actor controls the production and distribution of services in a value chain. For instance, an operator providing voice telephony services had integrated the service and network operator roles, thus maintaining complete control over the value chain. Although in these studies this integration has still been largely maintained, the modelling has been developed towards separating the service development and provisioning from the network coverage and capacity provisioning.

The presented studies provide new research results as quantitatively modelling the communications value network with full technological deployments; giving first techno-economic implementations of the new communications ecosystem thinking. More granular implementations, with several interlinked models describing the versatile business actors and their business scenarios, are left for further study.

In the first studies (Publications 1 and 2), the Service operator and the Network operator were combined, but in the latter ones (Publications 3 and 4) they were separated into two interacting models, making the service provisioning, and, on the other hand, the network operation, more explicit and easier to simulate the effects of the investments on the results of each actor. In our modelling, the Service operator actor includes also the VAS service provider and Billing service provider roles and pays subsidies to the Distributor role, which may be taken by the Service operator or a partner actor. The Content aggregator role may also be taken by the Service operator itself or played by a partner.

The regulator's actions are reflected in the license fee and related network rollout coverage and schedule requirements and regulations concerning the interplay between the Network operator and Service operator actors, whether they are inside the same company or co-operating partners.

The modelled actors and their roles and mutual relationships are described in Figure 3. The direction of the arrows in the business architecture represents the direction of service flow. The revenue flow is considered to be in the opposite direction. The ellipse represents an actor. An actor may take up one or more roles. The rectangular boxes within the ellipse represent the roles.

The business architecture is mapped to the technology architecture comprising of different devices (CPE), service provisioning machinery and network structures, as presented in the next section.

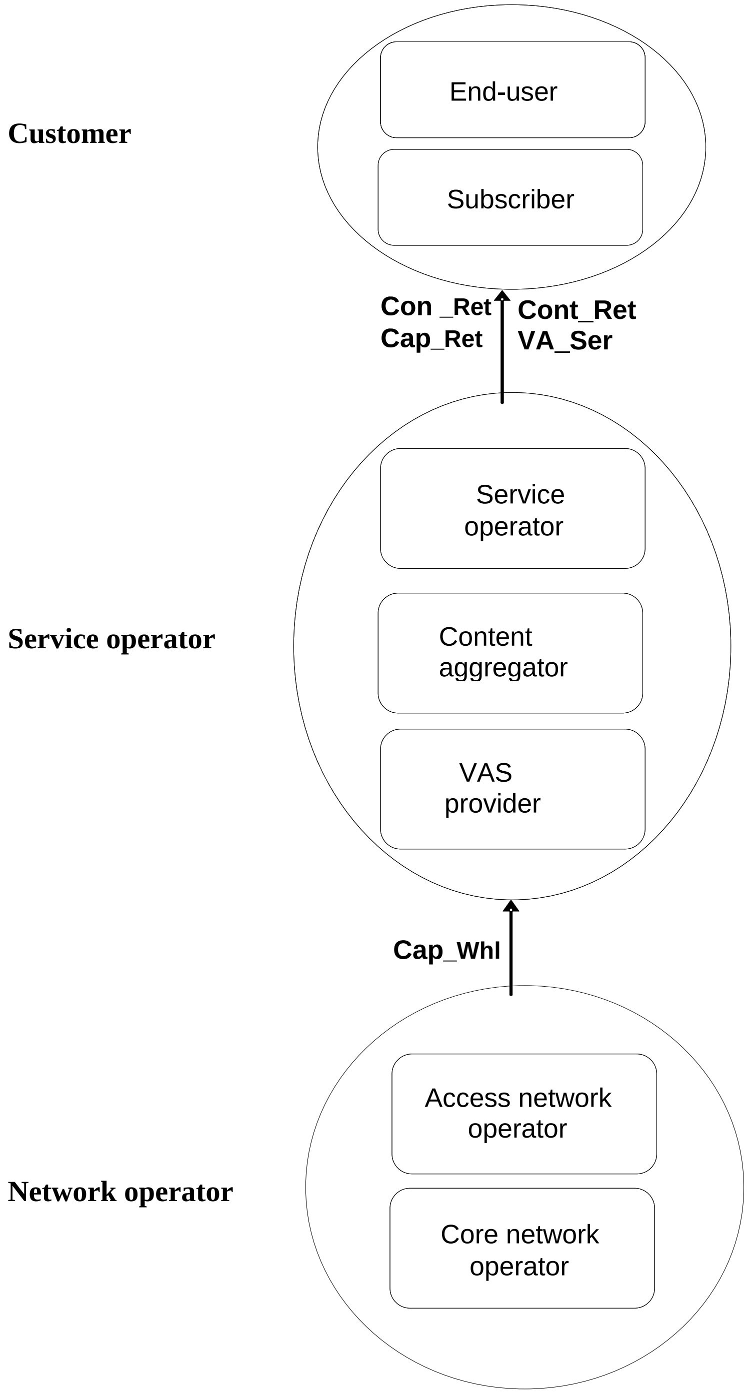


Figure 3: Service provisioning model with revenue interfaces (modified from ECOSYS Del. 3, 2004)

This business architecture reflects a basic service provisioning scenario, where the Customer buys services from the Service operator. The Customer can either be an individual or a business organisation. The Service operator acts as the main responsible actor towards the Customer, providing communications services like voice and video telephony, Internet access, as well as value-added services and content.

In order to reach its customers, and provide them with services, the Service operator needs to buy network access and transport services from the Network operator. The Network operator is modelled as an actor who operates both access and core portions of a network infrastructure. In our modelling, however, the transport network part is purchased as a leased line service from an external actor. The Service operator’s servers needed in service provisioning front-end may be situated in the Network operator’s core network or access network. The related technology architectures are described in the next section.

In this scenario, there exist three types of relationships between the actors:

1. A Customer enters into a contract (subscription) with the Service operator for the connection and usage of basic services. A contract for value added services is also possible. A Service operator may adopt different pricing models to charge for the services provided. The billing service is taken care of by the Service operator, thus incurring OPEX.
2. A Customer utilises services and content that may be billed per transaction or per consumed capacity or both.
3. A contract exists between the Service operator and the Network operator for the provisioning of transport, core and access network services. The contract requires provisioning of enough capacity and QoS, including charging service, etc.

It should be noted that the content and application production is not modelled explicitly, but the respective costs and prices are taken into account in the Service operator model and End-user model.

Table 3 lists the main revenue streams and cost drivers for the modelled business actors in this business architecture.

Table 3: Basic service provisioning: revenue and cost models

Actor	Roles	Revenue		Cost	
		Interface	Streams	Interface	Drivers
Service operator	Service operator	Con_Ret	Subscription and monthly fee from the subscriber for connectivity and basic services	Ser_Dstr Internal	Device subsidies, marketing & sales, customer care & billing, and IT support costs
		Cap_Ret	A variable fee for transmission and transactions	Cap_Whl NES_Ven Internal	Wholesale charges for network capability + capacity, server costs
	Content aggregator	Cont_Ret	Content fees	Cont_Whl NES_Ven Internal	Payments to the Content provider, server costs, marketing
	VASP	VA_Ser	Value added service fees	Cont_VAS NES_Ven, Internal	Payments to the Content provider, server costs, marketing
Network operator	Access network operator, Core network operator	Cap_Whl	Wholesale revenue from Service operator	NES_Ven Cap_Whl Internal	Equipment purchases, leased lines costs, operation & maint.

Although the external content providers and other value added application providers are not modelled separately their impact on the service provisioning ecosystem has been recognised as vital for the Service operator to be able to provide a lucrative service palette.

Neither the handset (device) vendor or distributor has been modelled separately, but the subsidisation of devices by the Service operator has been included in the modelling. This subsidisation may take place as the Service operator sells the devices in its shops as a bundled part of the subscription, or by subsidising the handset distributor/retailer. In the calculations the cost of devices sold has not been included, neither the related retail revenue; only the subvention part is included in the costs.

If the Service operator is a completely separated business actor from the Network operator, it can be considered as an MVNO (Mobile Virtual Network Operator). The contract between the infrastructure owner and the service provider is in this case far more challenging, as there are hardly any pure network infrastructure owners, but they are linked with the service provider arm, so that the MVNO is easily seen as a competitor. In this situation the revenue/cost margin is left too low for profitable MVNO business. This dilemma has been dealt with in Publication 4 and some of the referred MVNO studies (e.g. Katsianis et al. 2007). Meanwhile, in the presented infrastructure sharing studies, the co-operation between the business actors is on the network operator level.

In the integrated operator convergence study, the service provisioning machinery is modelled further, covering the service access and connection management as well as the application server aspects. The case studies indicate that more elaborate business architectures are needed to cover the most viable scenarios in the provisioning of the advanced services, as will be suggested in the conclusions chapter of the thesis.

2.2 Technology architectures

In all of the studied business cases, the thesis explores the techno-economics of a network infrastructure that supports an IP data networking, enabling users to receive a common set of services through different access technologies. The radio access technologies modelled in the case studies are UMTS/HSPA, WLAN and mobile WiMAX. As the technologies have been still in the development phase during the case studies, the TONIC and ECOSYS projects have utilized access to the research and product development knowledge inside the consortium in defining the detailed parameter values (e.g. capacity, capability and price) and their future evolution. The generic network model is described in Figure 4 below.

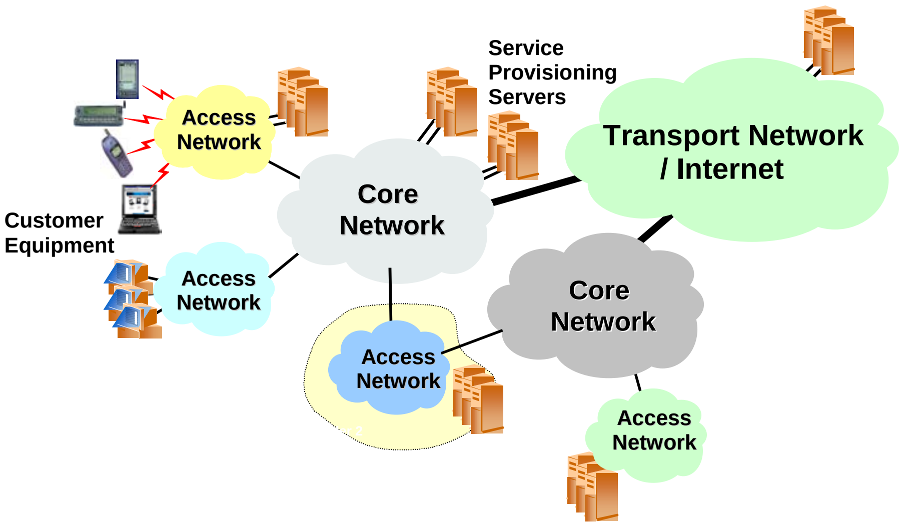


Figure 4: Generic Network Model (modified from TONIC Deliverable 11, 2002)

This generic network model comprises the following elements:

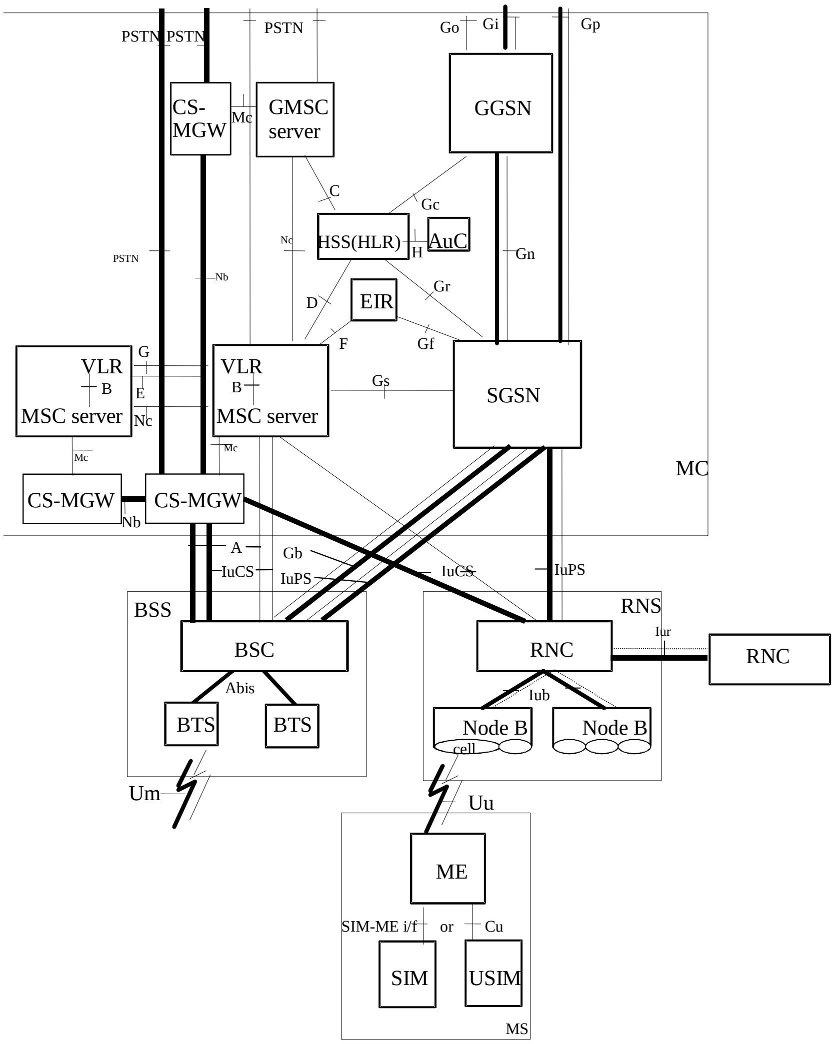
- **Access Network:** provides connection for the end-users' devices to the network. It can be based on wired or wireless technologies; could be mobile or fixed, private or public, etc. For example, the access network could be based on WLAN, UMTS, GSM, etc. The studied business cases focuses on access via UMTS and WLANs, or mobile WiMAX.
- **Transport Network:** provides the IP backbone and telephony PCM lines used to interconnect access networks, core networks and the Internet. The backhaul connections from the base stations to the radio network controllers (RNC) and the links between the core network elements are also considered to belong to the transport network. It is possible for an access network to be connected to two or more different core networks. The studied business case models the transmission costs arising from the forecasted transport traffic load as leased line costs, being part of the operational expenditure (OPEX).
- **Core Network:** provides the connectivity service for the subscribers to connect to each other and to the subscribed services. Among other things, it facilitates the network operation, signalling, routing, charging and subscriber management functions. The mobile core provides the mobility service and the fixed core the connectivity for the fixed access terminal equipment. The converged core caters for connecting the fixed and mobile services for converged services offering through, for instance, an IP Mobility System (IMS).
- **Service Provisioning Servers:** server pool to offer services, applications and content to end-users and/or other service providers. The services may range from traditional messaging and IP services like e-mail or web access to more advanced ones like m-commerce, value added information/entertainment services or applications, location based services, IP-telephony, videoconference or video-on-demand. The servers can be situated in the access network, core network or behind the Internet.

- **Customer equipment**: devices are used to connect to the mobile or fixed access network, to which there exists a subscription. Devices support different capabilities and capacities. In the convergence case, both a fixed and mobile device may utilise the same subscription. In some cases, the operator may decide to subsidise the cost of the device or necessary add-on modules. While this expense relates to the final link in the technical part of the network, it will be included among the sales and marketing expenses within the studied business cases. Mobile devices are developing to a more and more important part of the business/technology architecture combinations as their capabilities and communication capacities are increasing and services utilising these are being developed.

2.2.1 UMTS network architecture

The basic configuration of a UMTS/GPRS network as a Public Land Mobile Network (PLMN) supporting the interconnection to the Public Switched Telephone Network (PSTN) and Public Data Network (PDN) is presented in Figure 5. This configuration presents signalling and user traffic interfaces which can be found in the PLMN based on UMTS Release 4. Implementations of this architecture may differ: several functions may be handled in the same element thus some of the interfaces becoming internal interfaces. Interfaces A and Abis are defined in the GSM Technical Specifications and the others in the UMTS Technical Specifications. Both GSM and UMTS (WCDMA) are covered by 3GPP specifications (3GPP 2009).

Mobile core network (MC) and radio access network elements (BSS and RSS) are separated into their own boxes, as well as the mobile station (MS). The mobile core provides the connectivity to operation and maintenance centre (OMC) and to the application servers, as well as the interconnection to the PSTN/ISDN, PDN and external access network provider networks. An MVNO and application service provider (ASP) may own a varying amount of the core network elements that connect to the network provider's core network elements according to the interfaces presented, or the services may be provided through PSTN/ISDN and/or PDN (Gi interface), or through the Internet. Normally, an MVNO has at least own HSS/HLR to maintain its subscriber data, as a strategic competitive resource.



Legend:
Bold lines: interfaces supporting user traffic;
Thin/dashed lines: interfaces supporting signalling.

NOTE 1: The figure shows direct interconnections between the entities. The actual links may be provided by an underlying network (e.g. SS7 or IP).

NOTE 2: A (Gateway)MSC server and associated CS-MGW can be implemented as a single node: the (G)MSC.

NOTE 3: The Gn interface (between two SGSNs) is also part of the reference architecture, but is not shown for layout purposes only.

Figure 5: Basic Configuration of a UMTS PLMN supporting circuit and packet-switched services (modified from TONIC Deliverable 11, 2002)

In the case studies in Section 4.1, the UMTS network uses WCDMA/FDD (Wideband Code Division Multiple Access/Frequency Division Duplex) radio technology. As the studies in Publications 1 and 2 start from the year 2002, Release 99 is used in the first years of the study period, then through Release 4's MSC Server concept, towards an all-IP core network as standardised in 3GPP Release 5 specifications. In Publications 3 and 4, the upgrade to the HSPA (High Speed Packet Access) data transfer technology is introduced.

2.2.2 WLAN architecture

WLAN usage is part of the study setting and was first assumed to be based on enhanced HiperLAN/2 technology. The inter-working of these networks and the ability to seamlessly move among them is developed by the IST projects BRAIN (IST-BRAIN 2003) and MIND (Wisely 2003). The purpose of the combined UMTS/WLAN business case is to evaluate the economic implications if an inter-working technology were implemented on a nationwide scale and mapped to the business architecture of relevant actors.

The provision of seamless IP services through roaming between access networks like WLAN and Wide Area Cellular Network (e.g. UMTS), is illustrated in Figure 6. Connection handovers may be provided as the user moves to/from WLAN access point's coverage area.

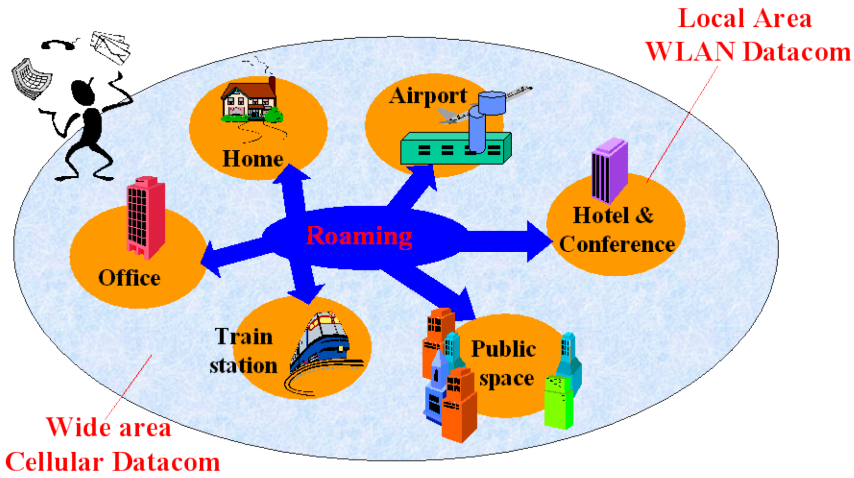


Figure 6: Concept for seamless IP provision through WLAN and UMTS (TONIC Del. 11, 2002)

While UMTS networks were still in the deployment stage during the study, WLANs were already launched for commercial service in hot spots like airports and major hotel chains in the United States and many European countries. These WLANs, based on the IEEE 802.11b standard, operated in the unlicensed 2.4 GHz band. The area (range of 100-150 meters) is covered by a radio Access Point (AP) which is connected to an Internet backbone via a high-speed wire line data link. The users in the coverage area shared the peak capacity of around 11 Mbps.

Although these systems were technically mature, quite well advanced from a market viewpoint, and had industry backing from major equipment vendors (Lucent, Cisco, 3Com, Nokia, among others), they were not the only solution for broadband wireless coverage. Other systems using the 2.4 GHz band included Home RF and future Bluetooth products, which were geared toward the residential market, with the potential to upgrade to higher bit rates. Another version of the IEEE standard, 802.11a, would operate in the unlicensed 5 GHz band and was expected to offer better performance in terms of capacity - up to 54 Mbps raw data rate - while avoiding the congestion problems expected to arise in the 2.4 GHz band.

In addition to the "Wireless Ethernet" 802.11 standards, the ETSI HiperLAN/2 (High performance Radio LAN) standard was expected to give rise to new products. This standard, which also operates in the unlicensed 5 GHz band and offers a data rate similar to that of 802.11a, was seen as a potential competitor to the IEEE standard. While their physical layers are similar, these two standards differ in the MAC layer, 802.11a retaining its Ethernet nature with a connectionless mode but HiperLAN/2 establishing connection-oriented links, which are specifically adapted to the type of content in terms of bandwidth, latency, error rate, etc.

It is also recalled that most UMTS operators in Europe have received, in addition to paired 5 MHz frequency bands, a 5 MHz unpaired band allocated to UMTS Time-Division Duplex (TDD) operation. This resource can also be utilised for high-capacity indoor coverage of hot spots, where it offers the advantage over WLAN as being in a licensed band, managed such that no competing and/or interfering system can operate in the same frequency. It is also better adapted to asymmetrical data flows than the FDD resource. It was also noticed that in the near future also the WCMDA/FDD mode would offer data optimised asymmetric capacity with HSPA technology.

One considered issue is the handovers between the WLAN and cellular mobile systems, UMTS in particular. This issue has not appeared crucial for private WLAN systems, which require a specific authentication when starting a session, but it has been addressed by certain UMTS equipment manufacturers and is also of key importance in the BRAIN/MIND architecture, which was utilised in the case study.

The BRAIN/MIND architecture introduces a Brain Mobility Gateway (BMG), which provides the handovers between the wide area UMTS network and the local area WLAN networks. It is a special purpose IP router hiding any BRAIN-specific routing functionality. BMG can connect a WLAN with the UTMS core, for example, via the GGSN (tight coupling) or via the Internet (no coupling). The previous alternative is lucrative especially if the same Network Provider owns both WLAN and UMTS access networks, but the later one gives most independency for separate business actors.

2.2.3 Mobile WiMAX architecture

WiMAX is based on a set of global standards covering fixed, portable, and mobile deployments. The two IEEE standards behind WiMAX are IEEE 802.16-2004 (Fixed WiMAX) and IEEE 802.16e-2005 (mobile WiMAX) which extends the Fixed WiMAX standard to include mobile wireless broadband at walking pace, so-called nomadic mobility and also to support full mobility.
The mobile WiMAX is optimised specifically for mobile broadband Internet access. The characteristics of the WiMAX technology include full IP compatibility throughout the network, and an effective OFDM radio frequency utilisation.

Cooperation on WiMAX extends across the industry. The expertise needed to evolve the ecosystem has been gathered under the WiMAX Forum, which is encouraging the adoption of WiMAX by establishing and promoting the WiMAX brand. The Forum also undertakes network architecture and related profile definitions. Major groups are investing in the development of chipsets, devices and other fundamental components. For the WiMAX technical specifications, see WiMAX Forum (2009).

The first mobile WiMAX deployments were aimed at the 2.5 GHz and 3.5 GHz licensed bands, with some in the 5.8 GHz unlicensed band. Licensed bands give stability and excellent service quality, particularly in dense urban environments. The lower frequencies provide better coverage with fewer base stations, which helps to reduce deployment and operational costs.

In the UMTS/WiMAX comparison studies (Publications 3 and 4), EDGE and UMTS technologies are modelled as evolution paths for GSM and GPRS technologies, but mobile WiMAX technology as representing an alternative technology approach for an incumbent operator without a UMTS license, though owning a GSM/EDGE (2G) network. Within both alternatives full GPRS coverage is already built, and EDGE technology is utilised for a fast initial upgrade for new services.

The same kind of site architecture is used for a mobile WiMAX network as for GSM/EDGE/UMTS. The WiMAX technical architecture is, however, somewhat streamlined for IP based service provisioning dividing into the Access Service Network and the Connectivity Service Network. The Access Service Network divides into mobile WiMAX Base Station and Access Service Network Gateway corresponding to BTS and RNC respectively. The Connectivity Service Network includes the core network elements as well as the OMC, and the application and support servers.

In Publications 3 and 4, mobile WiMAX (IEEE 802.16e) is deployed in the licensed 3.5 GHz spectrum. The width of the used frequency band is assumed to be 10 MHz. Although the WiMAX technology provides competitive strengths including full IP compatibility and effective frequency utilisation, the higher frequencies than UMTS shorten the range of the cells, making it more expensive to cover the suburban and rural areas with mobile WiMAX. However, in the urban areas the anticipated higher capacity per cell by WiMAX would give an advantage.

Competitive setting between mobile WiMAX and UMTS architectures

During the technical parameter estimation, mobile WiMAX was still under development and rather bold assumptions about its success, based on the spectral efficiency of the mobile WiMAX radio, were published: “With a scalable architecture, high data throughput and low cost of deployment Mobile WiMAX is a leading solution for wireless broadband services. By creating a common platform that addresses a wide range of market segments, Mobile WiMAX is well-positioned to experience a high global take rate.” (WiMAX Forum 2006) In this study, however, the user throughput in real life conditions will be simulated, as commercial deployments were not yet available and the business ecosystem is scrutinised to figure out the real industry development.

The same lack of real life data holds for the competing HSPA technology in the UMTS evolution path. The real user throughput of the utilised HSDPA BS configuration, with two 5 MHz channels per sector, is estimated to be 8Mbps. Respectively, based on simulations, the throughput is estimated to be at the level of 10Mbps for a 10MHz WiMAX base station, as an average in real-life conditions throughout the whole cell. These figures took into account the upcoming development, assuming at least two receiver (2-Rx) devices or even a multi-input-multi-output (MIMO) system. As downlink is the bottle neck for the assumed service mix, the uplink capacity development is not paid so detailed attention in the modelling, but in any case HSUPA is assumed to follow after HSDPA.

In the case study, UMTS is deployed with HSDPA capability from the beginning (year 2006) and the network is ready for use, starting from the densest areas, in the year 2007. The mobile WiMAX was estimated to be ready for deployment one year later and commercially launched in the beginning of 2008.

In the communications ecosystem, end-user devices have been usually that part of the end-to-end solution, which has lagged in availability. For example, there were commercial GSM networks up and running already in the year 1991, but the actual service launch was only possible in 1992, when reasonable handsets started to appear. The same situation was with early 3G technology in Europe in 2001, as the business actors were unsure of the start of the mass market development of the

UMTS handsets. For this reason attention has been placed on the handset availability as a crucial part of the total service.

The restricted availability and choice of the dual mode mobile WiMAX devices is reflected in the lower service adoption figures in the beginning. Also the HSDPA capable handset penetration grows gradually starting from 2006, so that the HSDPA extra capacity can be utilised only according to this user penetration.

As all the investigated technologies from GSM to UMTS/HSPA or WiMAX differ in parameters that affect the user behaviour like service adoption and usage, the modelling of these characteristics is of crucial importance. To analyse this effect, a separate End-user model with technology specific parameters is utilised.

Another important aspect in techno-economic comparison is the price evolution of the system elements. For the UMTS-WiMAX comparison the most significant element in the network side was found to be the base station. Cost is also an element that is challenging to estimate at the early phase. Cost evolution (decline) is very much dependent on volumes and thus there is a strong feedback loop from the competitive development of each technology.

Although WiMAX was designed aiming for cost optimisation for IP data transmission, the costs per 10 MHz mobile WiMAX base station is estimated to be roughly the same as for the plain UMTS 5+5 MHz BS configuration in the year 2006, due to the UMTS price erosion until that time. However, for a HSDPA capable network, an additional cost of 35% was assumed. The cost evolution model utilising learning curve expression that takes into account the produced volumes leads to annual price reduction of about 15% in the beginning of the study period for many network elements, including base stations.

2.2.4 IMS architecture

The IP Multimedia Subsystem (IMS) is an architectural framework for delivering Internet Protocol (IP) multimedia services. For an IMS architectural overview, see IMS in Wikipedia (2009) and for the IMS Specifications see 3GPP TS 23.228, IP Multimedia Subsystem, Stage 2, Release 8 (3GPP 2009). IMS originates from the GSM/UMTS standardisation, but has developed to a wide technology approach in combining the different fixed and mobile cores and to provide common mobile and fixed services. IMS is generally accepted to deliver carrier grade SIP-based session-oriented applications, including voice, dual-mode/FMC, unified messaging, presence, video sharing, enterprise integration (e.g. IP Centrex, Mobile PBX, Hosted Call Center), online and mobile games, group chat, and push-to-talk/push-to-video.

The IMS architecture used for the modelling is shown in Figure 7Figure 7, where functionalities are mapped to physical components. The user equipment (UE) accesses the IMS through an access network. The heart of the IMS system is the Call Session Controller (CSC). It is connected to a Home Subscriber Server (HSS) and two media controllers: the Media Resource Function Controller (MRFC) and Media Gateway Controller (MGC). The AS refers to a generic application solution which would basically be a service delivery platform (SDP) offering both operator’s own and third-party services. Support Functions (SF) are an estimate of necessary PS transfer (TSF) and business support system (BSS) upgrades due to IMS. Voice Call Continuity (VCC) functions are provided for seamless voice call handover in different access networks both in CS and PS domains, including

Supplementary Services support like Line Identification, Call Forwarding, and Call Barring. For related specifications, refer to TR 23.806 (3GPP 2009).

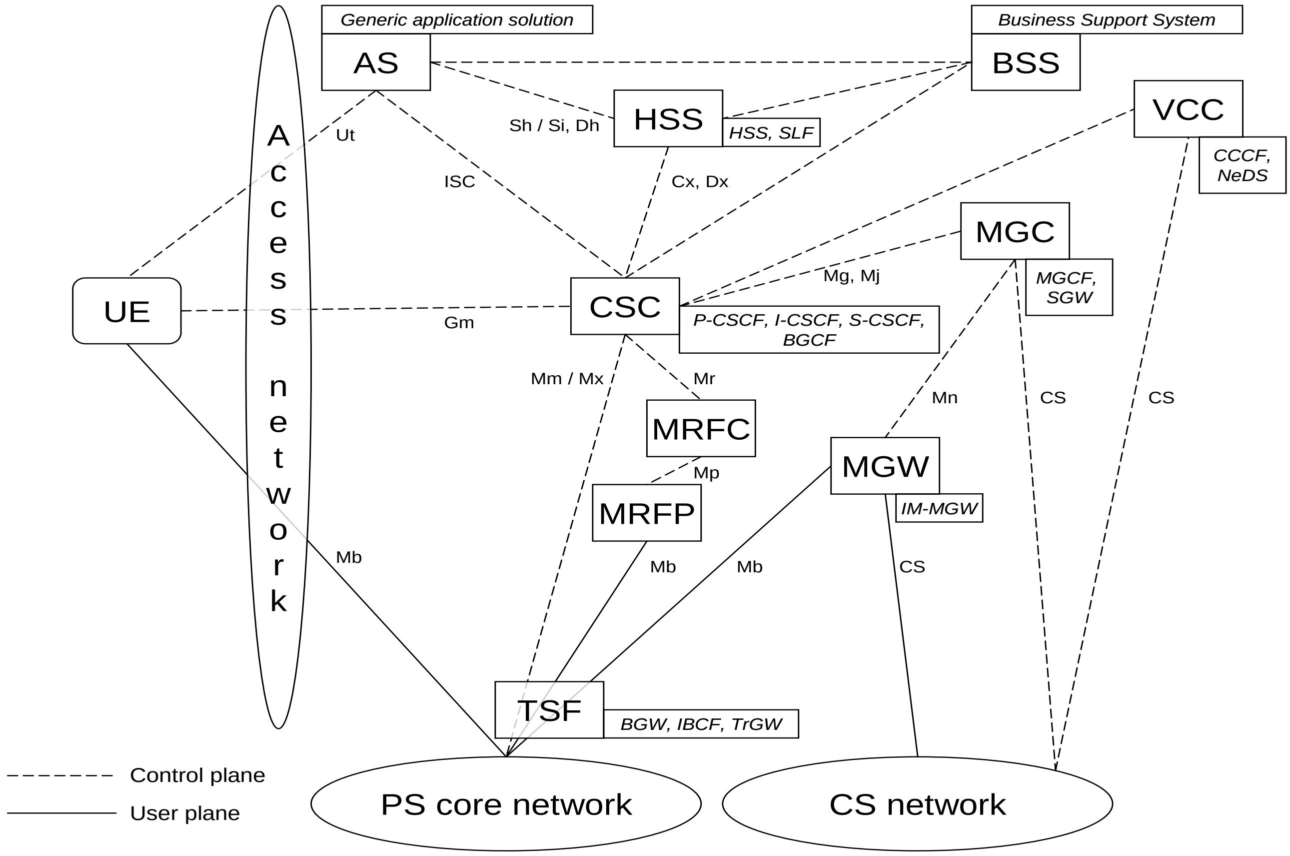


Figure 7: IMS architecture (Publication 6)

3. TECHNO-ECONOMIC METHOD

The basic idea in the techno-economic modelling utilised in this thesis is to gain a balanced view of the particular business case by combining the market, business and economic view with the technology characteristics. The plain market studies can easily go astray if the technology constraints or benefits are wrongly estimated. On the other hand, the purely technology-oriented studies, looking only at the benefits of certain technology or service, easily lead to overly optimistic scenarios, as the market behaviour and economic positions and interests of different actors (including the consumer) can in many cases overplay the pure technological advantages.

To analyse a mobile communications business case in the 3G and beyond era, several domains are needed to be combined:

- Services to be provided
- Competing/complementing end-to-end technology systems and their evolution paths
- Country/global regulation, geographies and demographics
- Market demand and end-user behaviour
- Business actors and the relative business architecture to make up a profitable business case from the previous factors

As noted in the previous chapter on business architectures, the former monolithic business modelling approach is no longer possible in the situation of converging communications, media, and IT industries, but different value networks and partnering schemes need to be considered for the provisioning of equipment, networks and services.

As it is not possible to list fully all potential new services, a classification is needed that supports:

- Service demand estimations and forecasts
- Separation to consumer and business markets
- Capability requirements (QoS, etc.) and capacity consumption
- Usage patterns to support, for instance, peak load estimation
- Schedules for needed end-to-end capabilities
- Relationship with devices and their user diffusion
- Required servers, middleware, applications
- Network requirements related to coverage and capacity
- Revenue potential (added value), price elasticity, revenue sharing
- Pricing schemes (e.g. transaction based, traffic based, flat rate)
- Substitution (cannibalisation) of other services

Each available technology branch (e.g. GSM/EDGE/UMTS, CDMA, WLAN, WiMAX, DVB-H) should be analysed to get information on which service classes are best supported by which technology, considering access devices, servers, and network capabilities, including factors like:

- always connected
- trusted authentication
- location information support
- fast transmission of large data amounts
- low cost broadcast
- cost of coverage, functionality and capacity (CAPEX, IMPEX and OPEX)

- interplay with and complementing to other technologies in provision of services
- end-to-end support
- roaming, handovers support
- backward compatibility
- future-proofness
- life-cycle of investments

.

Parameters relating to the specific market have to be defined for the actual case study:

- country demographics
- general market parameters
- own starting position and resources
- other business actors, their interests and strengths
- bargaining power in revenue sharing and procurement

However, service, technology and market analyses, even combined with the analysis of the actor's own position, cannot directly imply a business case to go for. A strategic vision and decisions are needed; business architecture should be found with a specific plan on how to build up a profitable business from the resources available. It requires cutting the service provisioning value chain or network into the possible roles and relationships and defining the value-adding activities and the revenue potential. These should lead to selection of service provisioning strategy, technical architecture deployment plan, pricing scheme, etc. The implemented techno-economic model can then be utilised to evaluate the case consistently, taking into account all the different dimensions of the business.

Techno-economic modelling is an iterative process, visiting certain aspects of the business over and over again, and fine-tuning the parameters that are in the control of the actor, or are dependent on its actions, or are dependent on the totality of the market development. If the modelling shows that a particular combination leads to suboptimal results, new combination of the choices should be considered. This process can be illustrated by Figure 8.

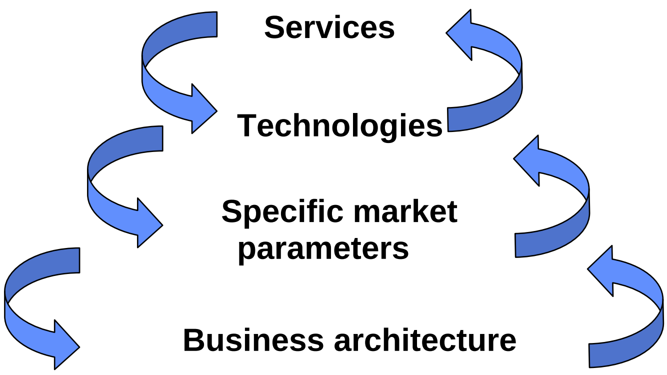


Figure 8: Iterative techno-economic modelling process

The techno-economic modelling process steps include:

- Selection of business architecture based on analysis of services, technologies and available co-operation strategies, taking into account specific market parameters
- Implementing a techno-economic framework model to integrate all dimensions affecting the investigated business case
- Definition of service classes provided and their characteristics and evolution throughout the study period
- Forecasts for technology diffusions, service demand and related revenue potential
- Modelling of different technology deployments and required investments
- Modelling of operating costs (including marketing and procured services from other actors)
- Calculation of key economic figures
- Performing simulations for risk and sensitivity analyses and possible real option analysis
- Adjustment of the parameters, introduction of different scenarios (model iteration)
- If models of several actors are linked together, the parameters are fine tuned to form a feasible whole and revenue share between the actors
- Comparing different business architectures and deployment plans to find the most feasible ones

3.1 Business case model

To cope with the abundance of different parameters in techno-economic modelling, a set of tools is needed. The generic modelling tool, built upon Microsoft Excel, and the analysis framework utilised in the studies of this thesis have been developed in a series of European co-operation projects. In addition to this generic telecommunications operator model, a specific End-user model is utilised in Publications 3 and 4 for analysing the end-user experience and benefit in relation to technology alternatives.

It is not possible to find in the present literature publications on other such kind of extensive models for mobile communications business cases. The published studies are typically focusing either on technology/cost aspects (like Johansson 2005: “Cost efficient provisioning of wireless access”) or business/revenue side (as Olla & Patel 2002: “A value chain model for mobile data service providers”) or some specific service. They provide valuable pieces of information, but are not covering the totality of the technical and business aspects of the full infrastructure and service provisioning scenario, which would be important for the large technology strategy decisions.

The modelling of the networks, devices and services comprises of hundreds of cost, capacity, performance, quality, usage and pricing, among other, parameters that are extensively covered in the documentation of the above mentioned projects.

The business case modelling does not concentrate on questions of the generic diffusion of the 3G and beyond services, but tries to estimate how the active deployment of the technology enhancements and respective new services affect the costs and revenues of the business actors. For the analysis of potential usage, resulting in new revenues, bottom-up analysis of foreseeable services and their value is used, in connection with the diffusion of related technologies and constraints in the general subscriber spending.

In the technology comparison cases (Publications 3 and 4) the End-user modelling is used for forecasting the service usage differences, basing on the understanding that the user tries to maximise his total net benefit. Benefit curves as well as opportunity cost (relating to the value of time) differ between the analysed segments. For example, the youth segment has the lowest opportunity cost to use the services, and the business segment respectively highest opportunity cost, i.e. value of the time.

In the technology comparison studies the service provider and network provider businesses have been analysed with separate models, both based on the same framework. The generic structure of the modelling is presented below in Figure 9, and the interfaces between the separate models in Figure 10. In the latter one, also the main inputs and outputs of the End-user model are presented.

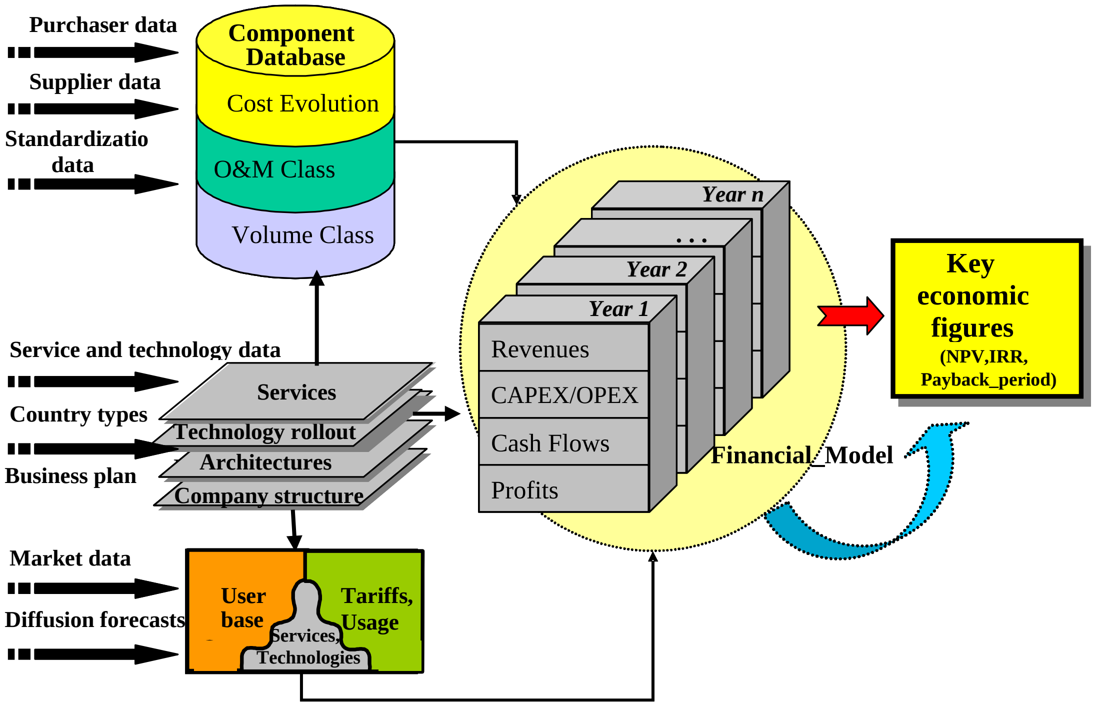


Figure 9: Operator model framework

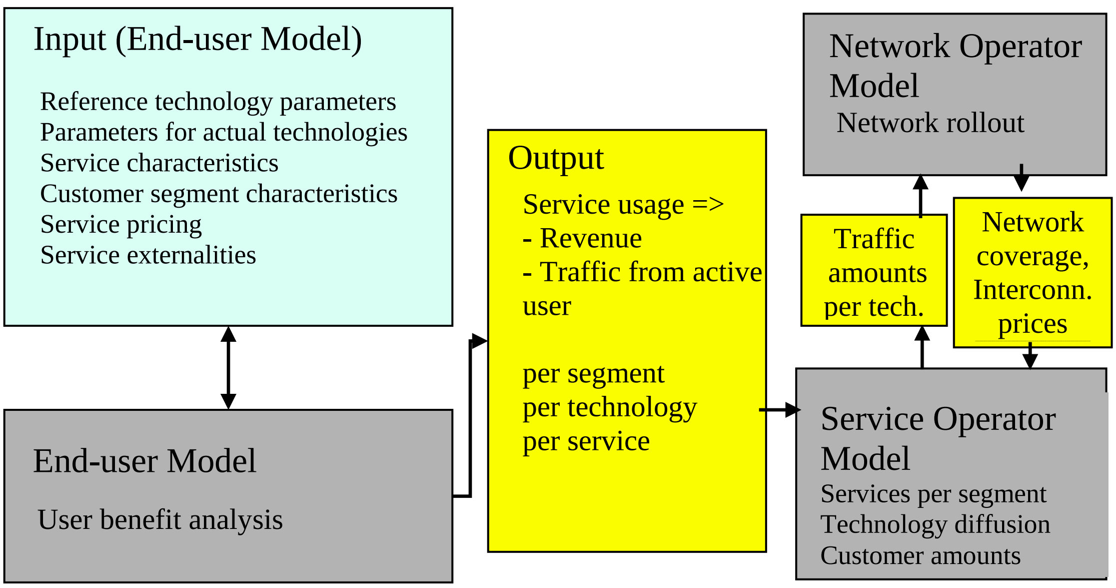


Figure 10: End-user model with interfaces between the models

The following subsections go deeper into the main modelling aspects and parameter estimation methods.

3.2 Technology diffusion forecasts

The demand or diffusion forecasts are essential inputs for all of the case studies. According to the general theory of technological innovation, diffusion will follow an S-shaped adoption curve. The adoption starts slowly, and then rises quickly as more and more users adopt the innovation, and finally levels off (Rogers, 1995). Diffusion model of Bass is very commonly used (Bass, 1969). There different country specific characteristics, like GDP, educational level and e.g. competitive or regulatory conditions, introduce different values for the diffusion parameters (Dekimpe, Parker and Sarvary, 2000; Gruber and Verboven, 2001). Especially concerning communication related innovations, the network externalities have been considered important (Gurbaxani, 1990). General diffusion modelling has mostly concentrated on the user behaviour, macroeconomic and policy aspects (e.g. Frank, 2004), but business actors and modelling their decision making in the micro economical level has not been focused in the analyses. Some studies, however, combine various aspects, discussing different stakeholders that contribute to the diffusion process (Saugstrup 2006).

Although general diffusion models are used in this study for diffusion of different mobile technology generations, for service diffusion it is assumed that a crucial hindrance for the mobile data service usage lies in the technology or service bottle necks, and that it is possible to accelerate the service adoption through provisioning of better user experience through enhanced technologies and applications. Other important factors in this context are pricing and marketing. The challenges in this whole are seen to be the reason for voice calls and plain SMS being for long time the only services adopted by majority of the mobile phone users in Europe. The factors affecting service usage and the potential demand have been quantified by end-user modelling, described below in Chapter 3.3 “Demand and revenue modelling”.

In telecommunications diffusion as well as other technology innovation diffusion modelling the Bass model and the related logistic models have been the most influential. The article introducing the Bass model was voted as one of the ten most influential titles of the Management Science journal’s first fifty years (Bass, 2004). Logistic model has been widely applied to the telecommunications diffusion. In the modelling of digital telecommunications diffusion, Gruber & Verboven (2001) estimate the logistic model parameters based on the econometrics of different countries. The study has difficulties, however, to estimate the saturation level because of lacking data, but ends up to suggest the level of 62% penetration stating that it “is slightly higher than most industry forecasts”. This error witnesses the difficulty in estimating the diffusion of life changing technology innovations, like new mobile generations, based on general economic parameters.

As the econometric parameters in this kind of technology cases are found to be difficult to analyse correctly for longer periods, another approach to model telecommunications diffusion is suggested by Kauffman & Techatassanasoontorn (2005), studying four defined diffusion states in the diffusion process and modelling the likelihood for the transition from state to state against technology and market specific parameters. But in the quantitative modelling of business cases it would be optimal, if we can achieve a function with only a few parameters providing forecasts matching with the market data. As history data of the mobile diffusion started to cumulate in the beginning of the 2000’s with maturing markets, it made possible to make estimations based on well-grounded vision on the mobile telecom market development rather than general econometric parameters.

The utilized diffusion models and forecasts for different telecommunications technologies and generations have been developed in a series of the European techno-economic projects, resulting in a logistic type of formula (Bewley et al. 1988, Stordahl et al. 1999). This model is found optimal for long-term forecasts and for new services or products. To achieve a good fit, four parameters, including the saturation level, are needed.

The model is defined by the following expression:

$$Y_t = M / (1 + \exp (\alpha + \beta t))^{\gamma} \qquad (1)$$

where the variables are as follows:

Y_t : Penetration (number of users / total population) at time t

M : Saturation level (potential users / total population)

t : Time (from the launch of the service)

α, β, γ : Estimated coefficients

The parameters α, β, γ cannot be estimated simultaneously by, for instance, ordinary least-squares regression since the model is non-linear in the parameters. Instead, a stepwise procedure is used to find the optimal parameter estimates. The resulting curves are valuated based on compilation of information from experiences of communications technology diffusion in earlier generations, most recent development statistics, external reports and market surveys.

The logistic model is used for the total mobile penetration as well as for each mobile technology generation. The parameters are estimated for each generation separately. For the UMTS subscriber penetration model, different Saturation level parameter M values are used for “Small country” business cases (M=95%), and for country type “Large” (M=90%). The other parameters are the same for both country types.
It should be noted that, although we are also tracking the number of subscriptions, as in many studies, we concentrate on the number of individual users, which is considered to be better in modelling the usage, revenue and traffic. Especially in some markets people may have many subscriptions for different kinds of use, and the penetration of mobile subscriptions can easily go over 100%. But the amount of subscriptions (SIM cards) per person does not increase the usage as such, as only one mobile device is utilised simultaneously.

This formula differs slightly from the logistic diffusion function (Mansfield 1961), which is usually expressed in the form:

$$Y_t = M / (1 + \exp - (\alpha + \beta t)). \qquad (2)$$

The Bass model on the adoption and diffusion of new products and technologies has been widely influential in the field of market analysis since its publication (Bass 1969). The Bass model can be presented by the following equation:

$$S_t = dY_t/dt = p + (q\text{-}p)Y_t – q/M *Y_t^2, \qquad (3)$$

where S_t denotes the sales rate at time *t*, and the parameter *p* represents the “innovation” coefficient and the parameter *q* the “imitation” coefficient. The idea in the model is that the “innovation” coefficient represents the marketing and other external effort promoting the product, being independent of the amount of users (or cumulative sales). The "imitation" coefficient represents the externality factor, i.e. internal promotion of the product by the users who have already adopted the product or service. Its effect on the probability of a potential user to adopt the product grows linearly with the amount of those who have already adopted the service until the saturation level is reached.

Assuming $Y_0 = 0$, the solution to the differential equation (3) is:

$$Y_t = M\ (1 - \exp -(p+q)\,t) / (1 + q/p \exp -(p+q)\,t). \qquad (4)$$

Differentiating the penetration Y_t in the logistic formula (2) leads to sales rate

$$\begin{aligned} dY_t/dt &= M\beta \exp - (\alpha + \beta t) / (1 + \exp - (\alpha + \beta t))^2 && \text{/substitute } Y_t = M / (1 + \exp - (\alpha + \beta t)) \\ &= \beta Y_t \exp - (\alpha + \beta t) / (1 + \exp - (\alpha + \beta t)) && \text{/substitute } Y_t = M / (1 + \exp - (\alpha + \beta t)) \\ &= (\beta/M)\, Y_t^2 \exp - (\alpha + \beta t) && / \, Y_t \exp - (\alpha + \beta t) = Y_t ([1 + \exp - (\alpha + \beta t)] - 1) = M - Y_t \\ &= (\beta/M)\, Y_t (M - Y_t) = \beta Y_t - (\beta/M)\, Y_t^2, \end{aligned}$$

that is equivalent with the Bass model (3) in the case, where the "innovation" parameter $p = 0$, and the "imitation" parameter q is denoted by β.

A logistic model can be criticised for the fact that it assumes more than zero adopters at t=0, as can be seen from the formulas (1) and (2). On the contrary the Bass model gives zero initial adopters, as can be seen by inserting t=0 into equation (4). In the initial stage, the parameter p gives solely the adoption rate in the Bass model. On the other hand, the reasoning behind the Bass model can be criticised because the effect of parameter p, the "innovation" influence, is as strong upon the last potential adopters in the end of the diffusion period as it was when the diffusion started - even when the saturation level has already been reached and thus the effect of the "imitation" parameter changed to negative, as can be seen from the equation (3). It would be more in accordance with intuition and practical behaviour of the market actors that when the user base is already almost maximal, the "innovation" parameter would have only a very slight impact anymore, as there is no news value anymore and no need to focus any advertising on the last laggards, but the diffusion is based solely on the influence of the large user population. The innovation and marketing efforts have already moved on to the next technology generations.

This holds particularly in the case of communications services, where new technology generations have followed each other before the saturation of the earlier generation. The modelling tracks the total mobile user penetration, as well as the diffusion of different technology generations as part of the total trend, so that the whole is consistent. This is done so that the early adopters of e.g. EDGE (2.5G) technology migrate to UMTS at the same time as the early followers are moving to use EDGE technology and the laggards have not even adopted the GPRS technology for data services, and so on.

For communications services the positive externalities are exceptionally high, because of the nature of, for instance, the communication and social networking related services. The term "externalities" relates actually to the "internal" influence in this context, as the value of the service increases rapidly as more and more people are connected or interacting through the service. The equation (1), used in the modelling, provides for a higher externality effect by the parameter γ. By utilising it, the initial phase can be made low-gradient but in the middle of the S-shape steeper than with the respectively fitted traditional logistic curve. These kinds of models have been quite successful in predicting the mobile communications diffusion (Michalakelis et al. 2008).

3.3 Demand and revenue modelling

3.3.1 Demand and revenue modelling based on service classification

Modelling of the revenues and related costs should start with analysis of the potential services. Detailed analysis of the different services can be found in the TONIC project Deliverable 1 (TONIC 2001-2002). That work forms the basis for the business cases analysed. The basic attributes of the introduced classification are based on the standardisation of the 3GPP, but the use cases and usage patterns that form the quantitative characteristics of the classes are unique contributions of the project.

In order to determine the impact of the various services on network dimensioning and revenue for the operator, service classes are defined in terms of bandwidth and quality of service. Each bandwidth class - narrowband, wideband and broadband - is assigned an average bit rate, which corresponds to the average air interface capacity required by a subscriber, when using the given service.

The four Quality of Service (QoS) classes used are:

- Conversational
- Streaming
- Interactive
- Background

The main characteristics of each class are indicated in Table 4. Definitions for Quality of Service Classes are provided in 3GPP specification 3G TS 23.107 (3GPP 2009):

Table 4: Quality of Service Classes as defined by 3GPP

Class	**Conversational**	**Streaming**	**Interactive**	**Background**
Characteristics	Delay and jitter controlled Constant bit rate Some bit errors allowed	Jitter controlled Near constant bit rate Some bit errors allowed	Enables question /answer exchange Low or no tolerance of errors Variable bit rate	No time constraint; Low/no error tolerance Variable bit rate
Examples	Voice, video-telephony, video-conferencing	Video, Audio	Web browsing, interactive e-mail	FTP, E-mail downloading as background task

For simplification, the Interactive and Background service classes are combined, considering that their requirements on the network were similar enough, and therefore not having any serious impact on network dimensioning and revenue expectations. Lastly, services are divided into circuit-switched and packet-switched services.

Based on these criteria, 11 service classes are defined. Depending on whether or not the operator owns only a UMTS network or both a UMTS network and a WLAN component, the service set is not the same. Indeed, the full “broadband” services were assumed to be initially available only through the WLAN component.

These classes are listed in Table 5 with examples of the services they encompass:

Table 5: Service classes for capacity estimation

Circuit / packet switched	**Bandwidth class**	**Quality of Service class**	**Sample services in the class**	**Nominal data rate (kbps)***	**Supporting network**
Circuit	Narrowband	Conversational	voice call	16	UMTS
Circuit	Wideband	Conversational	video call, enh. m-commerce	100	UMTS
Packet	Narrowband	Conversational	voice over IP	16	UMTS
Packet	Wideband	Conversational	video call, games	100	UMTS
Packet	Broadband	Conversational	video conference	227	WLAN
Packet	Narrowband	Streaming	audio clips (e.g. on rich call)	16	UMTS
Packet	Wideband	Streaming	video clips (e.g. on rich call)	100	UMTS
Packet	Broadband	Streaming	near video-on-demand	227	WLAN
Packet	Narrowband	Int_backgr	short msg., WAP	1.7	UMTS
Packet	Wideband	Int_backgr	e-mail, Internet	8.2	UMTS
Packet	Broadband	Int_backgr	large file transfers	107	WLAN

*average in the air interface over a typical usage session of the class, overhead included

Usage of each service class, in terms of average minutes per day, differs depending on whether the customer has a professional or residential profile. Lastly, the average busy hour consumption per user per service class is assumed to be 30% of total daily consumption for professionals and 20% of total daily consumption for residential customers.

The following Figure 11 summarises the procedures described above:

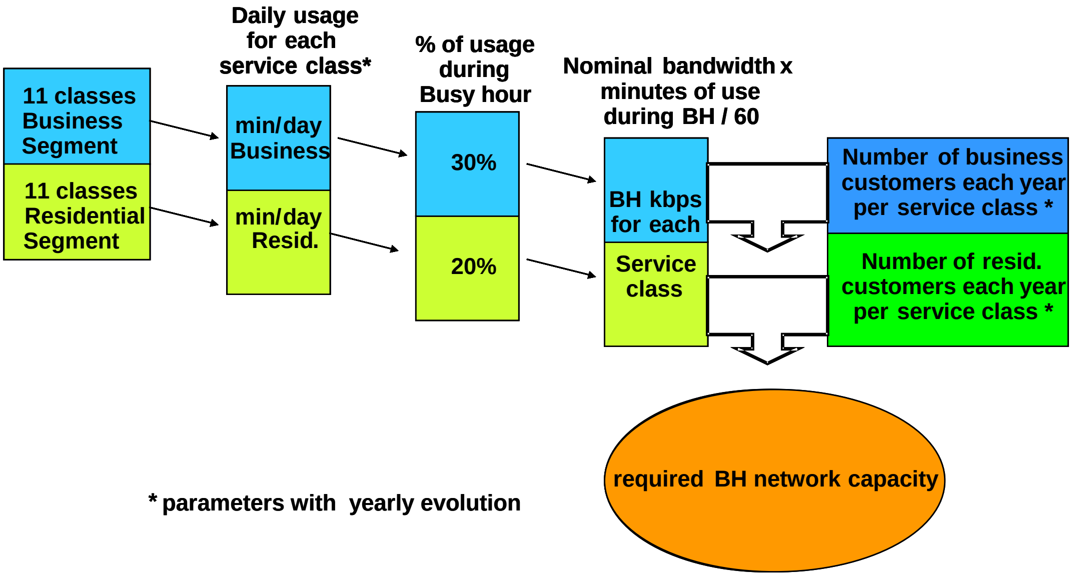


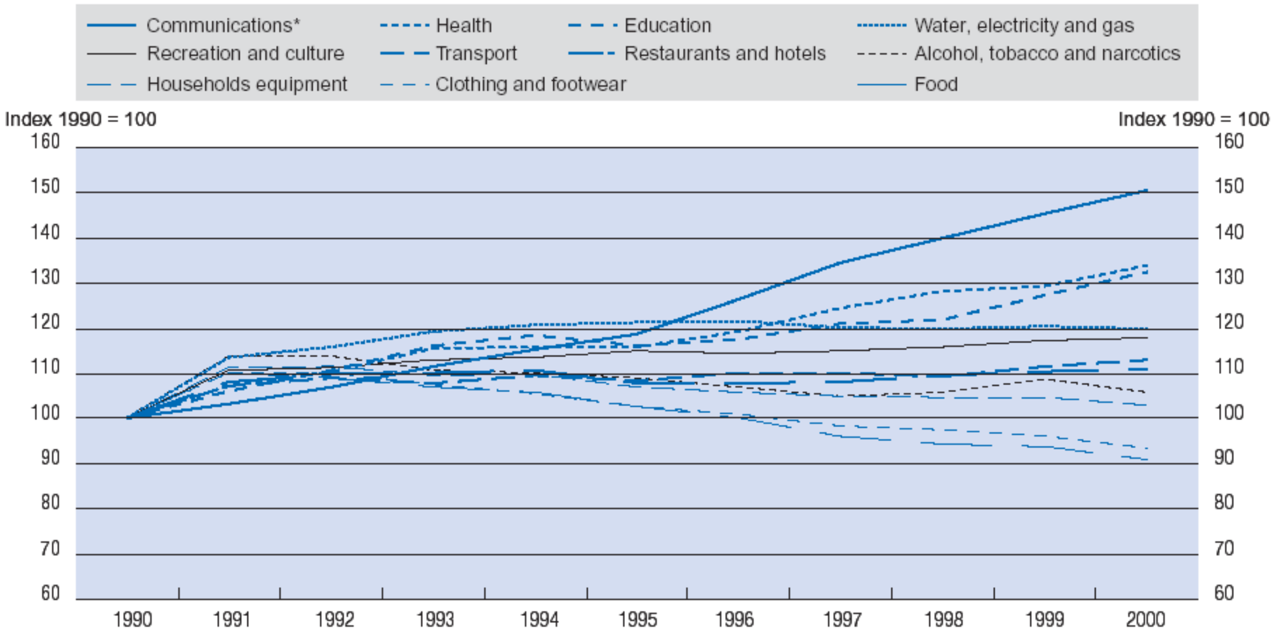
Figure 11: Procedure for calculating the required busy hour network capacity (TONIC Del. 11)

In the first studies (Publications 1 and 2) the revenue is based on the capacity and quality of service based tariffs in each service class, and the forecasted utilisation of the classes in business and residential segments. The pricing model is mainly cost based, the subscriber being charged according to the generated traffic in each service class. The tariff per traffic unit (kbit) in a service class is degrading yearly and is set lower for higher bandwidth technologies, because of the lower transmission cost per bit. The cost based pricing model can be criticised for neglecting price elasticity considerations. Some added-value services may enable high price level with low costs. A classical example of this is the SMS service, which has had very low costs for the operator compared to the end-user tariffs for the text messages. Therefore, there is also a traffic independent part for each service class that is used to reflect this kind of traffic independent added value.

Although the service analysis can provide a bottom-up perspective to the potential usage and revenues, it is important to ascertain that the totality of the spending by average user, or certain user segment, is in a reasonable range. There is limited purchasing power in each market and the available statistics relating to the spending division give the important top-down view on the possible total revenues for each industry segment.

The communications market was steadily growing during the last decade, and the money an average consumer spends on communications was increasing. In the OECD countries, the percentage of household consumption on Communications increased from the average of 1.6% to 2.3% (from USD 534 to USD 933 per year) between 1991 and 2000, according to OECD Communications Outlook statistics from the year 2003 (OECD 2003). This increase has been the most significant among all consumption sectors, as shown in Figure 12 below.

The first studies were done based on this strong growth trend and the resulting average revenue per user (ARPU) estimations followed this pattern. After the market downturn in the early 2000s, this optimism turned out to be a fallacy and the potential of the mobile services has not realised as anticipated. The later statistics from the OECD showed that after the year 2004 the consumption share of Communications even started to decline. In Publications 3 and 4, the current stagnation of the mobile ARPU has been taken into account.



* Communications include Telecom equipment and services and Postal services

Figure 12: Changes in the proportion of communication in disposable household income (OECD 2003)

3.3.2 Demand and revenue estimation supplemented with end-user usage modelling

In the UMTS/WiMAX technology comparison cases (Publications 3 and 4), in addition to the updated service analyses and segmentation, end-user modelling is used for forecasting the service usage differences.

Customer segmentation is one of the key aspects as estimating the market demand for services in the modelling. The subscribers are divided into four exclusive customer segments, defined as:

- Business users: Subscribers who regularly have their bill paid by their employer or regularly have the business element of the bill refunded by the employer
- Youth users: Subscribers of age 0 to 24
- Advanced users: The first 20% of subscribers to adopt newly launched services - out of those who are not Youth or Business users
- Basic users: Subscribers of age 25 or higher, who are not categorised as Advanced or Business users

The division between the segments differ country by country, but based on the data collected by the ECOSYS consortium (ECOSYS 2003-2007), the generic figures in Western Europe are set as follows:

- Business subscribers: 20%
- Youth subscribers: 20%
- Advanced subscribers: 20%
- Basic subscribers: 40%

The service charging is based on measures in minutes, transactions, transmission volume, etc., depending on service characteristics as illustrated in Table 6. Although the usage differs, the service prices are assumed to be, on average, the same for all segments.

Table 6: Service classification and pricing

Service	Description	Price unit	Price in 2005	Annual price reduction
Subscription	SIM card	€ /month	2,00	0 %
Voice	Make and receive calls	€ /min	0,08	15 %
Video call	Make and receive calls	€ /min	0,16	15 %
Push-to-talk over cellular	Make and receive calls	€ /min	0,05	10 %
SMS	Send and receive messages	€ /msg	0,08	5 %
MMS	Send and receive messages	€ /msg	0,24	10 %
Email	Retrieve and send Emails	€ /MB	0,80	20 %
Transactions	Ringtones, images, payments,..	€ / transact.	0,50	10 %
Downloads	E.g. music files and games	€ / transact.	1,00	20 %
Browsing	Browsing web sites and content	€ /MB	0,80	20 %
Streaming	Audio streaming	€ / MB	0,80	20 %
Other data	Business data etc.	€ / MB	0,80	20 %

Demand modelling is based on service diffusion and usage estimates for different technologies and segments. Technology diffusion forecasts are supplemented with specific end-user modelling that gives the correlation between the characteristics of different technologies and respective usage amounts (demand) by active users of each type of service (see Figure 10). The price level of a particular service class is one of the inputs to the end-user modelling. It is possible to make simulations with the end-user model and try to optimise the revenues with different price levels.

The end-user modelling is based on the understanding that the user tries to maximise his/her total net benefit. Benefit curves as well as the opportunity cost (relating to the perceived value of time) for using a particular service differs between the introduced segments. For example, the youth segment has the lowest opportunity cost to use services, and the business segment the highest opportunity cost. This is because of the difference in value of time for different segments. Thus, for example, delays in the connection have a higher impact on the usage of the business customer than on the youth segment subscriber.

The utilised End-user model is described in the following subsection, which gives the differences in usage volumes (demand) for active users of each service, caused by the differences in the characteristics of the analysed technologies. This analysis is done segment by segment. To get the average usage, also the share of active users of each service type needs to be estimated – within each segment and for each technology. Furthermore to get the total usage, revenue and capacity requirements of each service type we have to apply the knowledge about the market size and market share of the operator, technology penetrations, and even the rollout schedules, as for example data usage imposed by UMTS applies only where the UMTS network is available.

Estimated technology penetrations are based on device/handset user diffusions (see Section 3.1.2). The penetrations are estimated related to the business and technology plan of the operator, not as general technology penetrations, because there are always also operators, who do not promote certain technology. Therefore the technology penetration within the specific customer base may be much higher than the general penetration in the market. It has been assumed, for example, that if the operator promotes UMTS (with handset subsidisation), the heavy data users are quite soon migrating to utilise UMTS instead of EDGE in areas where it is possible.

Each technology induces slightly different penetrations for data services, so that higher capacity technology imposes more users, but this increase is for most services not as significant as the usage amount difference suggested by the End-user model. Only some services, like video telephony screens out the lower technology customers fully.

The Service operator's revenues are calculated based on usage amounts of each service type given by the modelling described above combined with the service prices that are degrading over time. Investments to deploy the advanced technologies increase the service revenues. The earlier the enhanced technology is deployed, the more revenue is generated, but only in the limits of general demand development and device availability. The generated average revenue per user (ARPU) is clearly higher for the more advanced technologies, but on the other hand, also the costs are higher for early capacity deployment, partly because of the discounting, but especially because of the equipment price degradation.

Most of the technology deployment costs fall on the Network operator, but it can transfer them to the Service operator as wholesale capacity tariffs. The techno-economic model helps in optimisation of schedules and pricing through simulations with different parameter sets. The Network operator's revenues are dependent on the success of the Service operator, as they are based on the traffic amounts calculated in the Service operator model. The wholesale tariff levels are set so that the operating profits of the Service operator and Network operator are at the same level in the UMTS case. The same wholesale tariffs per MB are then applied for all technologies. This means that the profitability may differ between the Network operator cases, depending on the cost structure and service demand arisen from the utilised technology. The cost calculation part of the model is described in the subsequent sections.

Wholesale prices that the Service operator pays to the Network operator are set for three categories: Narrowband conversational (voice/min), Wideband conversational (video telephony/min) and Data (per MB). A quite substantial annual price reduction of 15% has been applied, reflecting the assumed high increase of data traffic, which is to compensate for the lowering voice revenues.

End-user modelling method

The end-user modelling in Publications 3 and 4 is based on the approach in the ECOSYS project and is described in detail in ECOSYS Deliverable 9 (2005) and ECOSYS Deliverable 19 (2006). Description of the theoretical framework of the method can be found in Pohjola & Kilkki (2007). It is a novel approach in techno-economic modelling, and the presented studies are the first time, when this method is applied in a full mobile communications business case modelling.

The case studies that compare GSM/GPRS, EDGE, UMTS and WiMAX deployment strategies first define the key technology parameters related to the service performance. The parameter values differ between the technologies, mainly relating to the packet data communication features. Then a reference service level is specified for the parameters and estimated the average usage amounts with that service level in each segment. For these estimations, also the reference prices are set.

The End-user model is calibrated so that it gives usage amounts estimated to be reasonable throughout the study period as output for the parameters set on reference service level. The parameter values for reference service level can be those of one of the modelled technologies, e.g.

EDGE, or UMTS, but not necessarily. The reference level is chosen so that the estimation of the reference usage is as easy as possible.

In the End-user model, the usage amount of each service is calculated from the net benefit model for an average user in each segment. The net benefit model is based on the following micro-economic principles:

1) Diminishing marginal benefits. The more the end-user uses a service during a month, the less he will benefit from the additional usage unit
2) Opportunity cost. Limited time forces the end-user to make choices between different actions, for instance, to use the service or not. The opportunity cost of a choice is the lost potential net benefit from the best alternative choice
3) Cost – benefit analysis. The decision to use a service is based on a comparison of anticipated benefits and costs of using a service (opportunity costs plus monetary costs). End-user will use a service, if its benefits exceed the costs
4) Total net benefit. The difference between benefits and costs of usage during a month is the total net benefit for the end-user

In Figure 13 below, an example net benefit model for messaging type of service is presented. The benefit curve is inverse logarithmic and represents the benefits from the messaging service during one month for an average representative of one of the segments (1). The benefit is presented in monetary value (€). The assumption is that some messages are more important for the user than others, and thus more beneficial. The benefit curve is formed by arranging the messages during a month into the order of their benefit. On the vertical axis, in addition to benefit, we present also the opportunity cost for using the service. It is assumed to be the same for all of the messages (2). The service usage can be read on the horizontal axis below the intersection of the benefit curve and the opportunity cost line (3). The slashed area is the total net benefit for the user (4).

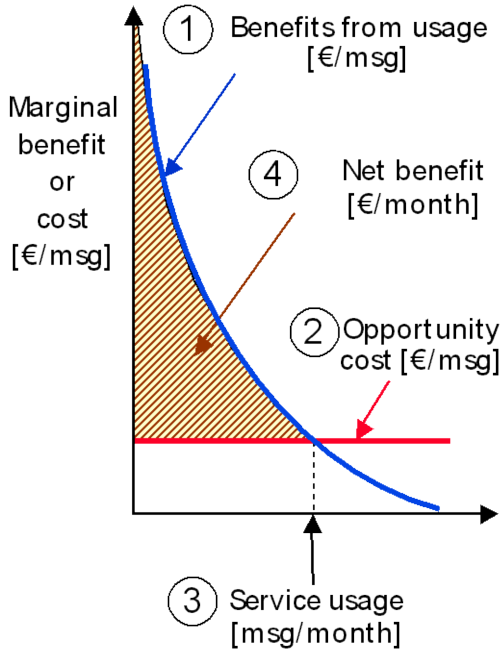


Figure 13: Net benefit model for a messaging service (ECOSYS Deliverable 11, 2005)

However, if each message has a price, we have to add the perceived cost upon the opportunity cost and draw a new line. This line intersects the benefit curve higher, thus decreasing the service usage.

In the End-user model, the differences in user experience between the reference technology and the deployed technology are analysed, and the changes in the user experience are transformed into changes in the end-user benefits and opportunity cost, resulting in a new usage amount and revenue for the operator. Each of the compared technologies in Publications 3 and 4 (GSM/GPRS, EDGE, UMTS and WiMAX) generates different usage patterns, traffic and revenues.

For example, lower speed of the service functioning may increase the time consumption for the user, thus increasing the opportunity cost, and decreasing the usage. On the other hand, increased quality of service by a more advanced technology in many cases increases the experienced benefit from the service, moving the benefit curve upwards and thus increasing the usage. Each customer segment has its own characteristic net benefit model, as, for instance, value of time and thus opportunity cost, capability/willingness to cope with technical challenges and thus experienced benefit, and, finally, perception of price level differs between the segments.

3.4 Technology deployments and required investments

For full techno-economic modelling also the full cost structure of the investigated business actors needs to be covered. On the highest level the costs can be divided into investments or capital expenditure (CAPEX) and operational expenditure (OPEX).

There is also a group of cost that are not actual investments on capital goods, neither operational costs, as yearly running costs of the business and infrastructure. They are usually called implementation expenditure (IMPEX). For communication networks, the IMPEX is quite substantial, even comparable to CAPEX, as the network equipment like antenna sites require a high installation workforce**.** As those costs are directly connected to the investments, we have included them into the cost database, and handled them as part of the CAPEX.

Operations are nowadays increasingly outsourced, affecting the cost structure inside the OPEX, but even parts of the infrastructure may be outsourced, shifting costs from CAPEX to OPEX. In our modelling, the infrastructure is not outsourced so that the investments are explicitly found in the CAPEX, with the exception of transport network, as the transmission links are modelled as leased lines which are part of the OPEX.

This section describes the method to model the investments costs, but part of the operating costs are directly linked to the equipment investment maintenance, and calculated utilising the component database information. The OPEX method is handled in the next section.

In the context of the Network operator and Service operator, the bulk of the investments fall on the network side, as contrary to the operational costs, which are more concentrated on the service provisioning side. Most of the service provider investments focus on the application servers, and other IT infrastructure, which is needed to manage the business processes and customer relationship.

For the network provider, the network rollout comprises the main part of the investments in our business cases. The coverage rollout comes first and then the capacity and functionality updates. To model the network rollout costs, we need to specify the country characteristics and the rollout schedule that depends on the business and regulatory requirements of the market.

3.4.1 Country characteristics

The studies model two generic country types, covering the main interests in the Western European market:

1) Large = Western European country like France, Germany, Italy, or UK
2) Nordic = Northern European country like Denmark, Finland, Norway, or Sweden

The country surface area is assumed to be 370 000 km^2 for the Large country and 330 000 km^2 for the Nordic country, corresponding to the average areas of the example countries. Also the total populations were chosen accordingly; 65 million for the Large country and 6 million for the Nordic country with very slight population growth.

People who live in the suburban/urban and rural areas are commuting into dense areas in the morning and return in the afternoon, thus causing much mobile traffic in the dense areas. Because of these special mobile communication characteristics, the normal demographic data on population density, based on residence cannot be used. Because the area data is used for the capacity rollout purposes, we are especially interested in usage habits during the peak hour whenever it forms in a particular area.

Due to the different population structure, the differences in the population density of different area types in Large and Nordic countries should be considered. For example, the dense area in the Nordic countries would resemble more the population density in urban areas in the Large countries, so that the generated traffic per square kilometre is higher. Therefore, the area types are handled differently within the two country types:

Dense urban areas
Typically, the dense areas consist of high buildings with shops on the first and second floors. These areas also include, for instance, shopping malls, funfairs, and sports arenas that must be dimensioned for high traffic densities. In the Nordic country, the major cities are estimated to have dense area coverage of only about 2 x 2km. In the Large country, there are more large cities, and the dense areas in them are bigger.

Urban areas
The urban area type surrounds all city centres and has a much larger coverage area. These areas typically have apartment houses of 3-10 floors on average. In Nordic countries, the number of floors is typically smaller than in the Large countries. Urban area is an area type where few people work and thereby do not generate as high peak traffic as in dense areas.

Suburban areas
Suburban areas typically have houses in rows and single residential buildings, separated by an average of 30-50 meters. These are typically areas outside urban areas housing people that work in urban and dense urban areas.

Rural areas
Rural areas typically have single houses with an average distance of more than 100m apart. The areas typically have small clusters of houses with about 5-30 houses around a little centre. Especially the roads need to be provided with continuous outdoor coverage.

Characteristics of the country types that are needed for the rollout modelling are presented in Table 7.

Table 7: Characteristics of Large and Nordic country types

Country Type	**Large**	**Nordic**
Total population in 2005	65 200 000	6 060 000
Population growth	0.3% per year	0.3% per year
Size of surface area of the country (km^2)	370 000	330 000
Size of dense urban area (km^2)	185	17
Size of urban area (km^2)	3 700	264
Size of suburban area (km^2)	37 000	3 300
Size of rural area (km^2)	303 400	264 000
Percentage of total peak hour traffic generated in the dense urban area	23%	15%
Percentage of total peak hour traffic generated in the urban area	45%	50%
Percentage of total peak hour traffic generated in the suburban area	24%	25%
Percentage of total peak hour traffic generated in the rural area	8%	10%

It should be noted that the overall size of the surface area is not the sum of all the sub-areas, because certain areas (e.g. lakes, mountain tops etc.) are not taken into account.

The traffic values in Table 7 are based on the data from the ECOSYS consortium (ECOSYS 2003-2007) and were calculated based on the principle that people in dense areas use communications services much more than in other area types due to major business and leisure use during the rush hours. However, the dense area is quite small especially in the Nordic type of country compared to the other area types, resulting to the fact that the urban areas require the build-out of highest total capacity. In the rural area the costs relate mainly to the coverage build-out.

3.4.2 Network architecture and dimensioning

As part of the techno-economic models, the dimensioning principles are introduced with the building blocks for the deployed technologies, including the evolution path for GSM and GPRS to EDGE, UMTS and HSDPA technologies, as well as the complementing/competing technologies in the studies, comprising WLAN in the first studies, and WiMAX in the latter ones. The investigated technologies have been introduced in Section 2.2 above.

Network dimensioning aims at calculating the optimal number of network elements (including nodes and links) that fulfils the capacity, coverage, and quality of service demands of the service area at minimal total costs (OPEX+CAPEX). As the technologies have been in the development phase during the case studies, the TONIC and ECOSYS projects have utilized access to the research and product development knowledge inside the consortium in defining the detailed parameter values (e.g. capacity, capability and costs) and their evolution in time. The presented capacity and coverage, as well as the initial cost figures are based on the data from the ECOSYS consortium (ECOSYS 2003-2007) comprising both vendor and operator view. The estimations for the radio performance parameters derive from the vendor simulations for each technology.

For the UMTS there are regulatory rollout requirements, which differ from country to country, and different schedules are applied to compare different scenarios and regulatory situations.

The first thing for the mobile service provisioning is to take care of the radio network coverage and the initial units of the core elements according to the business plan. The network deployment has to be started some time, usually about one year, before the service is started. In most study cases it takes one year to cover the dense area, two years for the urban, three years for the suburban, and 6-7 years to cover the whole rural area. In Publications 1 and 2 the building period started in the year 2002 from the dense areas, and usually the more sparsely populated areas follow always one year after the previous area type.

But as the schedule is parameterised in the model, also cases with faster deployment are studied. Especially in the Nordic country cases, where the regulatory requirements were in some cases very strict, it has been interesting to evaluate the economic effect of those rulings or the release of them. Also the effect of infrastructure sharing was studied by utilising the rollout parameterisation. In those cases the Network operator has to cover only part of the areas with its own radio network.

In the studies presented in Publications 3 and 4, the rollout starts as late as in 2006, when even the HSDPA technology is readily available and data traffic requirements have already grown. For this reason, the deployment starts at the same time in all other area types, but one year later for Rural area types.

The amount of base stations (BS) needed for the rollout is based on the cell ranges, which are handled in the dimensioning principles described below. Other equipment is counted accordingly, either based on BS amount, or the required capacity.

As the capacity requirements increase, the network dimensioning for capacity is modelled according to the following logic:

1) Traffic demands in different area types are calculated based on the service usage forecasts.
2) The number of radio base station sites and transceivers are calculated for each area type based on the cell range, amount of users within the cell area and capacity assumptions.
3) The number of core network elements like BSC/RNCs and MSCs, SGSNs, GGSNs is calculated from the base station amount, generated traffic load and subscriber/user amount based on the network element capacities.
4) The number of backhaul and core transmission links (BTS-BSC, BSC-MSC, MSC-MSC) is calculated based on network architecture, generated traffic, and available link capacities. Transport network is not built by the operator themselves, but leased, and the costs are thus included in the operational expenses.
5) The number of OMC-related and value-added service elements is calculated based on capacity figures relating to number of transactions, service requests, messages, and users. In some cases, just one element is needed per operator.

The generic UMTS network architecture and main building blocks used in the modelling is presented in Figure 14, showing also the mapping of different network elements to certain sites in the architecture. Our modelling considers four different kinds of equipment sites to exist. The BTS sites are housing the radio base station equipment, radio transceivers (TRx), and related mast, cabling, and antenna equipment. The BSC/RNC sites house the base station controllers, whereas the MSC sites are housing the switching equipment. Centralised OMC sites are housing all the support systems and servers.

The connectivity of the WLAN access points to the UMTS network was discussed in Section 2.2. Similar site architecture used for UMTS is used for the mobile WiMAX network. It is however somewhat simplified being divided into the Access Service Network and the Connectivity Service Network. The Access Service Network is divides into the mobile WiMAX Base Station and Access Service Network Gateway corresponding to BTS and RNC respectively. The Connectivity Service Network includes the core network elements as well as the OMC and support servers.

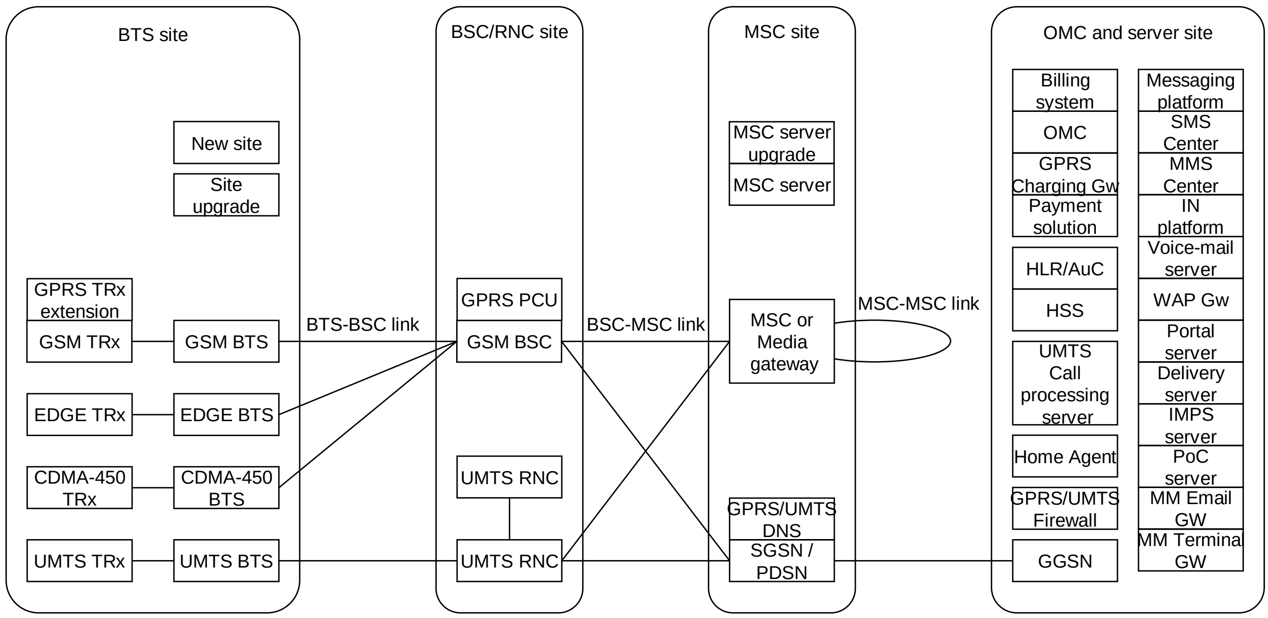


Figure 14: UMTS network architecture (Publication 4)

All the equipment investments as well as the related implementation cost elements are included in the component data base. It comprises also the cost evolution, maintenance and repair related data, specific to each element type. For cost evolution and for equipment maintenance and repair refer to the respective sections below.

Radio network elements account for about two thirds of the total network investments. Table 8 shows, as an example, assumptions regarding the cost and capacity characteristics of some of the key UMTS network elements. All of the radio access, core network, operation and support centre, and value-added service related elements and prices are included in the component data base of the model, with the specific capacity information. Dimensioning and thus investment cost calculations are based on different capacity measures for different element types, as demonstrated in the table. Some of the elements are upgradable for additional capacity or functionality, but some are not.

Table 8: Network element capacity related prices

Component	Reference Price 2005	Capacity
Radio access network		
3G Site Build Out	110 000 (no price reduct.)	Price per new site
UMTS BS Site Installation	35 000 (no price reduct.)	Upgrade to existing GSM site, no active equipment
UMTS BS	34 000	3 sectors x 2 bands, max 6 TRx per sector, max 18 TRx per BS
UMTS TRx extension	6 600	800 kbps (real av. throughput)
UMTS BS with HSDPA	46 000	3 sectors * 2 * 5MHz carriers
UMTS RNC	1 300 000	Max. 100 UMTS BS per RNC, Max. 250 Mbps
Core network		
UMTS HSS	4 000 000	1 000 000 customers
Authentication Server	290 000	1 per operator
UMTS MSC Server	1 700 000	1 000 000 customers
UMTS MSC upgrade	1 300 000	1 000 000 customers
GPRS and UMTS DNS	8 900	1 per SGSN
GPRS and UMTS GGSN Server	280 000	1 000 000 customers / 1000 Mbps
UMTS SGSN Server Basic	880 000	1 000 000 customers / 1000 Mbps
Value-added services		
SMS Center	400 000	1 per operator
IN Platform	2 300 000	1 per operator
IMS server	10	per user
Operation and support systems		
UMTS_OMC	4 000 000	1 000 000 customers, 830 Base stations (3 cells per BS)

For radio network dimensioning, additional assumptions are needed for coverage and throughput calculations. Examples for UMTS and mobile WiMAX are given in Table 9 below. The throughput figures are intending to describe the average bit rates, throughout the cell under realistic conditions, shared by the simultaneous users. In mobile WiMAX and HSDPA cases the applied bit rate is forward looking and requires devices with multiple receiver antennas (2-Rx) or even multiple input /multiple output (MIMO) antennas. The throughput values were based on the best available simulation results, trying to avoid pre-implementation state theoretical values that are usually too optimistic.

Table 9: Radio network dimensioning parameters

Technology	Frequency band (MHz)	Channel bandwidth	Throughput per channel (average, DL)	Cell range* (km)			
				Dense urban	Urban	Suburban	Rural
UMTS/ WCDMA	1900/2100	5 MHz (x 2 channels/sector)	96 calls / 800 kbps	0.57	0.89	2.11	6.36
HSDPA	1900/2100	5 MHz (x 2 channels/sector)	4 Mbps**	0.57	0.89	2.11	6.36 (not implemented)
Mobile WiMAX	3400	10 MHz	10 Mbps**	0.40	0.60	1.10 (not implemented)	3.00 (not implemented)

* three sector cells, indoor coverage probability 80%, also outdoor coverage might be relevant in certain later described cases

** slightly optimistic in relation to current vendor simulations against realistic conditions, takes into account the future development; at least 2-Rx or MIMO devices assumed

The base stations are modelled as providing for three sectors, each providing for a hexagonal cell. The BTS coverage is calculated from the cell range as described in Figure 15.

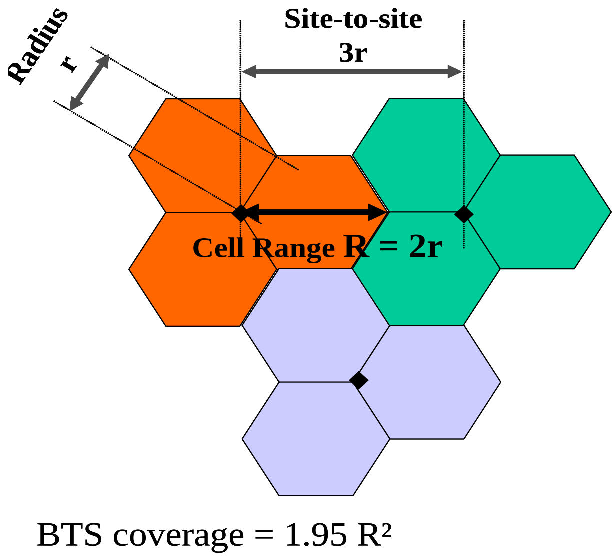


Figure 15: Cell range definition and BTS coverage calculation (ECOSYS Deliverable 11, 2005)

3.4.3 Cost evolution model

The component data base includes cost evolution data of all the equipment investmets and the related implementation cost elements. The cost evolution curves are calculated for each element according to this information.

Price evolution predictions utilise a learning curve model suggested by an earlier EU funded project RACE-TITAN, based on Wright's empiric law: "Each time the cumulated units production doubles, the unit cost decreases with a constant percentage" (Wright 1936). The learning curve model of Wright and Crawford (Crawford 1944) was further developed by Olsen and Stordahl to cope with the demands set by techno-economic modelling, where it is important to be able to predict the cost evolution as a function of time, not as function of produced units. In their formulation (5) presented below, they combine the learning curve model with a logistic diffusion model, which models the lifecycle of the component (Olsen & Stordahl 1994; Olsen & Stordahl 2004). The advantage of this model is that it can be used when only a few price observations of particular equipment are available, as the general technology trends of comparable elements can be applied.

The utilised learning curve can be expressed in the form:

$$P(t) = P(0) \cdot \left[\frac{1}{n(0)} \cdot \left\{ 1 + \exp\left[\ln\left(\frac{1}{n(0)} - 1 \right) - \frac{2 \cdot \ln(9)}{\Delta T} \cdot t \right] \right\}^{-1} \right]^{\log_2(K)} \qquad (5)$$

The past experiences within the EU IST techno-economic projects give knowledge about the feasible value ranges for the parameters in the formula (5). On the other hand, the price evolution can change notably due to competition and the economic situation of the industry.

The value of n(0) in the formula reflects the relative accumulative production volume in the reference year (0). From estimations for communication network components, n(0) could be 0.1 for mature products and 0.01 for new components in the market. P(0) is the price in the reference year, ΔT is the time for the accumulated component volume to grow from 10 % to 90 %. This is to describe the main part of the lifecycle of the component. K is the learning curve coefficient that causes reduction in price when the production volume is doubled.

The value of n(0) has been 0.01 for almost all electronic units in our models, as the reference years have been taken from the early period of the unit lifecycle. The K factor is 1 if the price level does not change. This has been the case for implementation costs. For site build-out it has been set to 1.1 indicating growing costs during the time. For electronic units, it has been set to a value of 0.8 in all presented studies. The value of the ΔT parameter has been set to 10 years, which can be seen as the historical time period between the waves of the succeeding major mobile generations (2G, 3G, 4G).

The ICT industry downturn in early 2000 with the heavy competition between the market actors and technology alternatives affected some notable changes, although not very significant, on the learning curve parameters. For many UMTS elements, like base stations, the annual price reduction given by the learning curve modelling of the case studies in Section 4.2 was about 14% in the beginning of the study period, instead of 12% that was given by the parameter values used in the earlier studies, presented in Section 4.1.

3.5 Modelling of operating costs

On the contrary to investments, most of the operating costs (OPEX) fall on the Service operator side, according to our techno-economic model. For techno-economic analysis, the operating costs have been clearly more challenging to model than the equipment investments. It is relatively easy to get information about the architectures, components and their capacities; they are generally open information, although the price data can be quite sensitive.

The OPEX composition, on the contrary, is strategic data for the business actors, and is not easy to get. The telecommunications operators do not publish their data at that level, but generalised data was achieved through the ECOSYS project partners (operators, equipment vendor, academia and consultancies, ECOSYS 2003-2007). The achieved decomposition can be regarded as a satisfactory approximation for the case purposes of the operational cost structures of modelled type of actors in the 3G era. Although some public studies handle the operational costs of some type of services or networks, there are no publications suggesting to fully cover the cost structure in the mobile communications business.

The latter studies (Publications 3 and 4) particularly concentrate on the OPEX structure of the telecommunications operator, making also the separation between the service provisioning part and the network provisioning part. But most of the calculation principles were the same as in the first studies.

For an operator providing 3G networks and services, the average total OPEX is considered to be higher than for the current (2G) operators, since the new network technologies and services require increased resources in all of the OPEX groups mentioned above. During the last 10 years the average European GSM operator OPEX (per subscriber) has decreased to less than a half. This is due to maturing technology and networks, increased process automation, growing subscriber amounts, and, in general, the advance in the learning curve and the pressure of competition.

Based on the OPEX data collected from the annual reports published by the operators, but taking into account the above highlighted 3G and beyond special trends, it is ended up to suggest as feasibility boundary values for the general average OPEX the monthly level of 13€ - 39€ per subscriber, depending on the market, operator type, technology and business architecture.

The current Western European generic division of total Network and Service operator OPEX for reference in the case studies is:

- Network related elements 20%
- Marketing and sales related elements 26%
- Customer service related elements 8%
- IT, support and service development 11%
- Interconnection and roaming costs 35%

In the beginning of the study period the model should give an OPEX closer to the higher end of the presented interval per 3G subscriber, but later as the 3G customer penetration rises and technologies mature, it should approach the lower limit. This development should naturally be dependent on the specific approach the operator selects, e.g. developing high-end services as a forerunner, or selecting to be a low cost follower. The interconnection and roaming costs are mostly bilateral, and the counterparties account for the termination fees for their part. This expense element is reducing for the regulated, lowering, termination and roaming tariffs and for the traffic shifting from handset-to-handset mode towards handset-to-Internet. For newcomer operators increasing their market share, the customer acquisition costs are naturally higher compared to established operators. Different parts of the model should be in balance for each scenario.

The OPEX estimation of monthly costs per subscriber is further adjusted by focusing on the more detailed OPEX items listed above, utilising the knowledge and history data on the GSM operators. Here again there is much variance between different kinds of operators. Established operators, having a large customer base, have an advantage over small entrants for some items, like marketing, but on the other hand the small actors may have very lean and effective customer care and service provisioning structure.

Low GDP per capita clearly lowers both the average personnel hour cost and the ARPU, but the labour efficiency is related with subscriber amount growth and company maturity in the market. Diverse competition strategies are available that affect immediately one or more of the OPEX groups: high or low network quality, large or small marketing investments, good or moderate customer service, etc. Again good techno-economic modelling requires the balance inside the holistic model. All the parameters (cost and revenue items) should be visible and adjustable for simulations.

The ICT downturn and increased cost competition has pressed the employee amounts of the Western European telecommunications operators down, as can be seen in the annual reports. Thus the employee costs are going down as the processes are made more effective utilising more advanced supporting IT systems. Also outsourcing has increased reducing the employee costs. This trend has affected both the Network operator and the Service operator side. In the former, the employee amount is modelled related to the number and complexity of the network elements, and in the later, is related to the number of subscribers.

Costs relating to supporting IT systems are growing relating to two factors. More and more complex and versatile network and device technologies require the management and support of an increasing amount of interfaces and end-to-end services. This, in turn, requires developed support systems with interconnection between the Network operator and Service operator sides. On the other hand, streamlining and automating the business processes to reduce the labour costs transfer costs into the increasing amount of IT systems and services, which can be partly or fully outsourced.

3.5.1 Network operator OPEX

The termination and roaming costs make up a substantial part of the OPEX in the Network operator's profit and loss statement in the beginning of the study period, but are decreasing as the voice call tariffs are reducing and revenues and costs migrating to the data services and traffic. They as well as the related revenues are not modelled explicitly in the later case studies, where the OPEX is broken down to cost elements. The termination revenues and costs are assumed to largely compensate for each other due to the increasing share of mobile telephony and regulatory control over price discrimination between access networks. Roaming has had high profit margin, but it is going through radical changes in Western Europe due to EU regulation and initiatives of large operator coalitions.

The operational expense profiles in the models differ between technology solutions, but not so much as is the case with investments. The differences originate from the different site amounts to be deployed. As the Network operator is not selling to the end-users, or supporting the end-user services, the operational costs are related mainly to site rentals, leased line costs, network operation & maintenance, and supporting IT systems, all relating mainly to the number of network elements, and leased line costs also to the traffic amount.

An example of high-level operational costs breakdown, giving some guidance on the impact of different OPEX elements, is presented in Figure 16 below. Subsequently the premises in the estimation of these cost elements are presented.

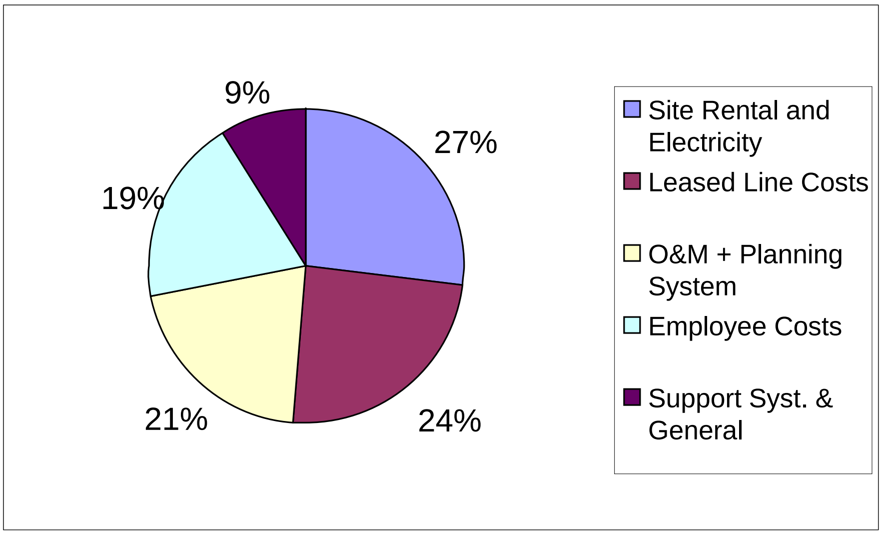


Figure 16: OPEX breakdown for the Network operator (Publication 3)

3.5.1.1 Site rental

Site rental costs are the largest cost category for the Network operator. The cost per base station site depends on the area type where the site resides. In dense urban areas, the rent of the space is higher, but in the rural area the organisation of the electricity is more expensive and the antennas are higher requiring ownership of the land space, maybe even a private road. The applied monthly costs per type of site are based on the ECOSYS operator data. The average rentals have increase over the years. In the first studies the starting (year 2003) site rental cost, including electricity, was 8 000 € / year per base station site, and in the latest studies the average cost, taking into account the distribution between different area type sites, was 15 000 € / year (2006).

3.5.1.2 Leased lines

The costs relating to the base station back haul and transport network connecting the BSC sites and core sites are modelled as leased lines and thus included into the operational expenditures. After calculating the required number of base station sites and BSC/RNC sites in each area type, as well as core network elements according to the principles described above (Network architecture and dimensioning), the number of core sites (MSC sites) and their interconnection links are modelled as follows:

- Nordic country: 4 nodes, 6 links
- Large country: 15 nodes, 23 links

A higher number of links than nodes assures that one link breakdown does not isolate any node. As an example, Figure 17 illustrates the Nordic country case.

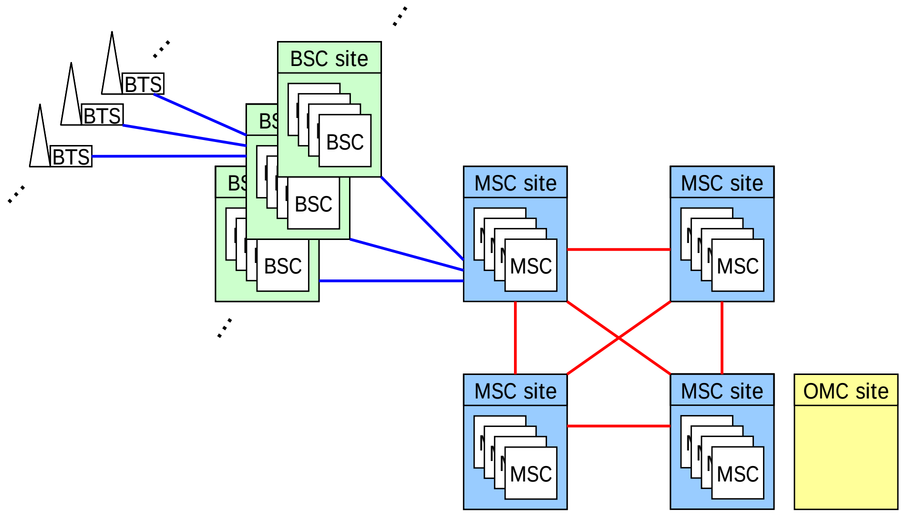


Figure 17: Simplified network architecture (Nordic country) (ECOSYS Deliverable 11)

The number of links between one base station site and the controlling RNC/BSC is calculated based on the assumptions of Table 10. Normally several links are needed for the UMTS and EDGE base station sites.

Table 10: BS/BTS – RNC/BSC link dimensioning rules

UMTS Carriers (TRx) Per 2M link	1.5
EDGE Carriers (TRx) Per 2M link	10
GSM Carriers (TRx) Per 2M link	15

The number of links between an RNC/BSC and MSC site is calculated according to the traffic originating per RNC/BSC. As 155 Mbps links are used here, normally one link per RNC/BSC is enough. All the links between base station, RNC/BSC, and MSC sites are assumed to be provided by leased lines. The required leased line lengths are calculated based on the assumptions shown in Table 11.

Table 11: Geographical distances between the key network components

Distances (km)	Dense urban	Urban	Suburban	Rural
BS/BTS – RNC/BSC	2	10	40 (Nordic) 20 (Large)	60 (Nordic) 30 (Large)
RNC/BSC – MSC (Nordic country)	20	40	70	100
RNC/BSC – MSC (Large country)	10	20	35	50
MSC – MSC	$= 2 * \sqrt{\frac{CountryArea(km2)}{\pi * NumberOfMSCs}} = \begin{cases} 324km, Nordic\_country \\ 177km, Large\_country \end{cases}$			

When the exact number of transmission links and their lengths (node distances) are known for each year, the related leased line costs (OPEX) are calculated according to Table 12.

Table 12: Leased line tariff assumptions

Capacity	Basic price per line / year (2005)	Additional price per km / year (2005)
2Mbit/s (BS/BTS – RNC/BSC)	5 400 €	486 € (Large) 240 € (Nordic)
155 Mbit/s (RNC/BSC – MSC)	16 913 €	1920 €
Up to 10Gbit/s	-	3144 €

The leased line prices in different countries may vary quite much. The above 2 Mbps leased line price is an estimated average value for short 2 Mbps lines based on Western European operator price lists in the study year. The initial price level for the shortest 2 Mbit/s lines are slightly higher than the recommendation in the European Commission "Recommendation on the pricing of short-distance leased lines" (European Commission 1999), but the prices for higher capacity lines (32 Mbit/s and up) are lower. The prices take into account also the "Published retail prices for leased lines" in the same document. The price/km drops significantly with length. However it is estimated that most 2 Mbps lines are within a length of 30 km due to a clustering of inhabitants also in rural areas. The same reasoning lies behind the 155Mb/s prices.

Due to the much smaller number of leased lines in the Nordic country, the average length of 2 Mbps lease lines is higher and the cost decreases as described above.

3.5.1.3 O&M

The network operation and maintenance approach is divided into three separate components:

1) The cost of repair parts.
2) The cost of repair work.
3) The operation, administration and network planning costs, other than the equipment maintenance - related to the number and complexity of critical network components and introduction of new technologies.

The formula for calculating O&M cost is:

$$(O\,\&\,M)_i = \frac{V_{i-1}+V_i}{2}\cdot\left(P_i \cdot R_{class} + P_l \cdot \frac{MTTR}{MTBR}\right) + OA$$

The first term in the right side in parenthesis represents the cost of repair parts; the second term is the cost of repair work, while OA represents the operation, administration and network planning costs. V_i is the equipment volume in the year i, P_i is the price of cost item in the year i, R_{class} is the maintenance cost percentage out of the equipment price for every cost component, P_l is the cost of one repair work hour, *MTTR* is the mean time to repair for the cost item in question and *MTBR* is the mean time between repairs for the cost item in question.

In order to implement the calculation of the O&M cost in the model, the MTTR and MTBR are defined for each equipment cost item in the component database.

3.5.2 Service operator OPEX

The Service operator's most important OPEX cost item in the model is the wholesale charges paid to the Network operator. This cost is increasing as the traffic is heavily growing as the advanced technologies are deployed, in spite of the decreasing wholesale tariffs between the Network operator and Service operator. The tariffs are assumed to be technology independent for both wholesale and retail services. However, the technology has an effect on the traffic amounts and thus on total revenues and to a smaller degree also on the total costs.

The second most important operational cost item for the Service operator is related to sales and marketing. The following items are in the order of magnitude: device subsidies, IT support and service development costs, and customer service related elements. OPEX items other than wholesale charges relate in the Service operator model mainly to the number of different technology subscribers, but also to the amount of acquired new technology customers. Device subsidies relate solely to the yearly numbers of new customers migrating to EDGE, UMTS or WiMAX technology. Some of the OPEX related items are presented in Table 13 below.

Table 13: Some Service operator OPEX items

Sales and marketing related elements	
Customer acquisition	75 € per new and churned customer
UMTS handset subsidy	200 € per new and churned customer*
WiMAX handset subsidy	300 € per new and churned customer*
EDGE handset subsidy	150 € per new and churned customer*
Customer service related elements	
Billing	5€ - 35€ per customer per year (depending e.g. on the number of prepaid customers)
Other customer care	15€ - 20€ per customer per year (using average number of customers in each year)

* cost erosion assumed

In the estimation of the 3G and beyond services' business cases, same kind OPEX trends are considered as with the earlier 2G generation, taking into account the product development, provisioning and customer support of the new data-related services, which form a much more complicated structure than the basic GSM services, mainly voice and SMS. The new end-to-end networking technologies require also increasing support system resources especially in the early period before maturing. Not forgetting that marketing and device subsidies per subscriber are at the highest, when the services and technologies are first introduced, as also the device prices are higher and the operator needs to give incentives for the customers to migrate to the new technology. For these reasons, the costs are modelled as eroding along learning curves.

3.6 Calculation of key economic figures

The objective of each business case is to estimate the related investments, revenue streams, and operational expenditures to be able to evaluate the case or "project". For this purpose, the Discounted Cash Flow (DCF) method that has been the traditional technique used for years by industries is used (Brealey & Myers1996).

Yearly cash flows are divided with a specific discount factor for every year back to the starting year to get the “present” value of the later cash flows. The discount rate reflects the time-value of money – the later money is less worthy than the present money. The applied discount rate is higher than the risk-free interest rate, as it reflects the general riskiness of this kind of projects – the unsure profits are less worthy than the guaranteed income. The applied discount rate has been generally 15%. The tracked investments, OPEX and the revenue streams form together the yearly cash flows that give with the discount rate the basis to judge the business case successfulness, using at least one of the following key figures:

1) The Discounted Cash Balance at the end of the study period gives a good view on the profitability of the case. The accumulated net cash flow (revenues less costs) in the final year is discounted to get its value at the starting point of the project. It, however, does not look at the future cash flows after that point, which may be important for the case evaluation, especially if the acquired assets are very valuable for the future business. On the other hand, if the study period has been chosen correctly, the comparison of business approaches can be justified based on cash balances, if the rest values are comparable between the cases.
   In many cases the cash flow patterns themselves give more information than the end result only, as, for example, a deep dive to negative cash balance requires financing capacity but then a long stay on the negative side requires patience as an investor.
   A typical discounted cash balance curve for a Network operator scenario goes first deeply down to the negative side because of the high initial investments. In many cases the cash flow turns positive fairly soon and the cash balance curve starts to rise. The lowest point in the cash balance curve gives the amount of funding required for the project. The point in time when the cash balance turns positive gives the Payback Period for the project. For a Service operator, the investments are smaller and not affecting the cash balance so much, but the relation between revenues and operational expenditure dominates the cash balance development.
2) The Net Present Value (NPV) is the present value of the future net cash flows (revenues less costs), discounted using the before mentioned discount rate. If the NPV is positive, the project is judged profitable. The Net Present Value gives a single figure of merit for a project, appreciated by most economists. In the case studies, the cash flows are not modelled up to eternity, but the rest value of the assets is put upon the discounted cash balance. The rest value here only takes into account the depreciated value of the investments, not the future revenue potential.
3) The Internal Rate of Return (IRR) is calculated as the discount factor that gives a zero-NPV. A higher IRR means higher profitability and better return on investment. IRR is a useful meter in a case where the scenarios to be compared are of different size and scope, for example, if the size of the networks is different. In these cases, the scenarios cannot be easily compared using Net Present Values, but the Internal Rate of Return gives a good indication of the relative profitability levels of the scenarios.
4) The Pay Back Period can be easily seen from the discounted cash balance curve. It is the time from the start (first investments) of the project to the point where the discounted cash balance intersects the zero-level, thus the business case first reaches a positive outcome. Pay Back Period is appreciated in many cases, as the more distant future is more unsure, but the Pay Back Period should be in controllable limits, however lucrative the development could be after that. The communication network related projects investigated are, nevertheless, heavy infrastructure investment projects, where Pay Back Periods are rather long by nature.

These figures do not express the risk related to a certain result, which makes them insufficient as such to give full judgement for a case. Even a high profit project can disqualify if the risks are intolerable for the business actor. For this reason, risk and sensitivity analyses are usually incorporated in the studies.

Another factor relating to the results and risks is the possible flexibility. As with risk analyses, it is recognised that the cash flows are not deterministic, derived from definite assumptions, but the assumptions may be handled as probability distributions with certain likeliest values. But with flexibility in some investment decision points, the worst cases can probably be avoided and the upside possibilities maximised. For this purpose real option analysis is utilised to get somewhat more reliable values for the presented key figures.

3.7 Risk and sensitivity analyses

The forecasts and results are based on estimations of future parameter values that in many cases are rather uncertain, as, for example, the market and technology development is not accurately predictable. For this reason, it is important to investigate which are the most significant parameters to effect the results (sensitivity), and what are the probabilities to end up with significantly lower profits, or even negative results (risk analysis). For the methods applied in modelling risk and sensitivity, see Mun (2006a).

In the sensitivity analysis, the model results are calculated with Monte Carlo simulation with a set of model input parameters that are varied using a multiplier with normal distribution and mean at 1 (see Figure 18 below). The effect of each parameter on the results is compared to others, and then the parameters are listed in the order of significance and their proportional impact on the result is presented. Another method used was to modify the parameters by, for example, +/- 50% in order to evaluate their impact on the results. This method is cruder, but gives information not only about the proportional impact, but also about the absolute value range the key figure can attain.

In the risk analysis, the distribution curve of the key result, derived through the parameter simulation is presented (see Figure 19). The curve is normally not symmetric, as the parameter effects are not necessarily linear or otherwise symmetric. This is because, for example, the increase of some revenue related parameter, like usage, may increase also some costs, but only in situations where a capacity upgrade is needed. The total variance, as the net effect of all parameter variations, is presented to reflect, in a way, the "volatility" of the particular business case. It is supplemented in later studies with Value at Risk (VaR) measurements, commonly used for financial portfolios (ECOSYS Deliverable 11 2005). VaR reflects here the riskiness of the business case, and presents the result that is lower than 95% (q = 5%) of the stochastically calculated possible results. So it represents the result that can at least be reached with high certainty.

For the sensitivity and risk analyses, Monte Carlo simulations were run using the Crystal Ball™ software. Parameters were varied stochastically according to Normal distribution with the following settings: Mean = 1.00, Std. Dev. = 0.10, Trials = 1 000.

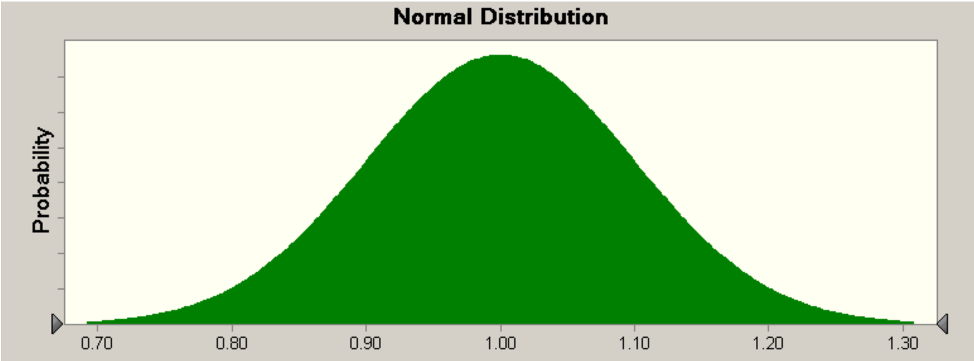


Figure 18: Graph of the applied normal distribution (from Crystal Ball™)

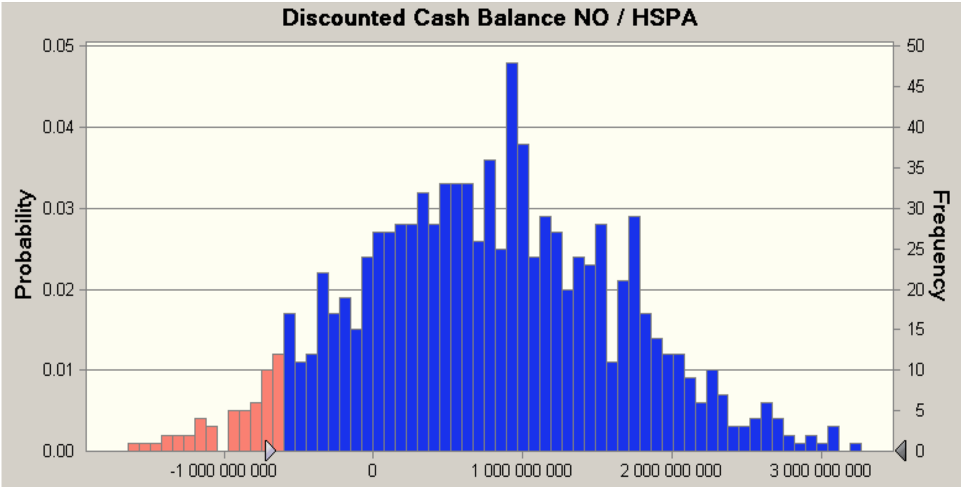


Figure 19: Example graph of the result distribution (from Crystal Ball™)

In addition to these quite formal parameter variations, a heuristic analysis of potentially the most important risks is done.

In the early studies of UMTS cases, the highest risk was generally the possibility of delay of the UMTS breakthrough. The foreseen reasons for the delay of the UMTS adoption were identified as:

1) general lack of demand, lack of interesting or useful applications and services
2) lack of willingness to pay for communications services (esp. mass market mobile data services)
3) technology immaturity
4) unavailability of equipment
5) too high price level and
6) weak economic position of the interest parties

The reasons were most likely a combination of these, coupled with unwillingness to take the risk of initiative by the actors.

By simulation of the service launch moving forward, sensitivity graphs are acquired, describing the payback time and the NPV against the delay. They illustrate the effect on results, when the investments are done according to the original plan, but the demand (penetration) curve moves ahead in time. Two scenarios were depicted; one where the cashing period of the UMTS is considered to be extended with the same shift as the delay, and another where the life-cycle end of the system was fixed. Both scenarios can be argued for and against, as the difference can be in the total pace of market and technology development, or just in 3G, which may even give boost for the next wave (4G).

The sensitivity graphs can be used to demonstrate that a delay of some years is bearable, but especially in the later scenario, even slightly more than two years may be too much.

Also for the risk analysis simulations a parameter for delay variation is introduced. Most of the uncertain input parameters may increase or decrease and the case may become better or worse as the parameter varies around the estimated most probable value. This is not the case with the diffusion start-up point, as it is not possible to make it earlier, for the rollout cannot be advanced, so that the variation may take only values describing delay, but not advancement. We have set the penetration delay to follow the exponential distribution (see Figure 20). This means that the mean or median of the possible case results is not the basic case result (with zero delay), which is however the one seen as the most probable individual outcome.

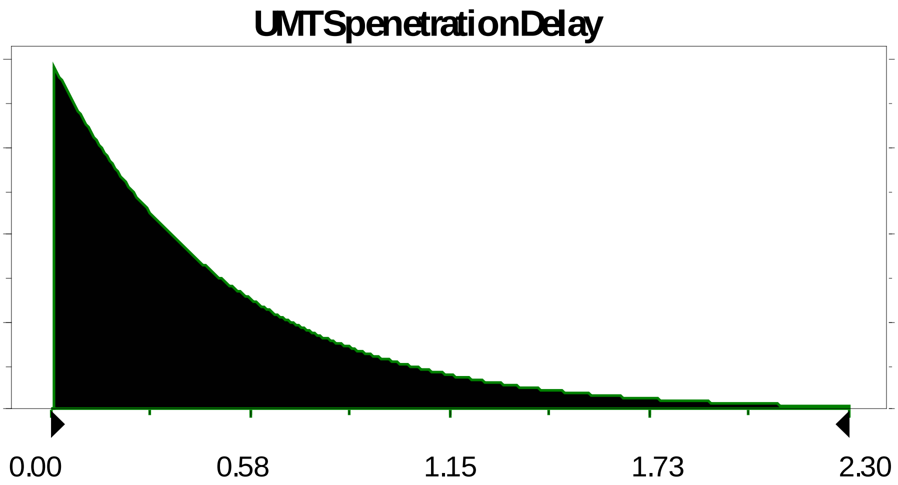


Figure 20: Graph of the applied exponential distribution of the delay (from Crystal Ball™)

In the later UMTS/WiMAX comparison cases, where UMTS launch has already taken place and that is not anymore an unsure parameter, an assumption was made that, as the mobile WiMAX launch timetable was not yet secured, the “WiMAX penetration delay” - parameter follows the exponential distribution. The delay was assumed also to have an effect on the “End market share” - parameter, as the competitive advantage moves towards the UMTS technology path. In this case the “End market share” multiplier is directly correlated with the “WiMAX penetration delay” so that it goes from 1 to 0.5 as the “WiMAX penetration delay” goes from 0 to 1 year. The rate parameter used in the exponential distribution is chosen to be 3.00.

3.8 Real Options approach as an enhancement to traditional T-E method

In order to valuate returns on specific assets, especially large investments (like building a new communications network), the traditional DCF technique with NPV calculation has captured the dominant position among corporations some decades ago (Shall et al. 1978). However, later also the drawbacks of this technique have become apparent as it cannot fully cope with the flexibility that is inherent in the management decisions in many cases. As a result, firms sometimes invest in projects, which have a negative NPV because they think they are "strategic", meaning that they see the investment as an important stepping stone for the potential future prospects, even though they might cancel or redirect the project at some later point, if the development takes an unfavourable path (Myers 1977). Some time after the introduction of the Black-Scholes formula to calculate stock option values in Black & Sholes (1973), the same kind of market portfolio approach was adopted to valuate corporate projects (real options) in Myers & Ruback (1987).

In the presented study, a lattice modelling is used instead of Black-Scholes, as the lattice method demonstrates more explicitly and concretely the development of uncertainty and the possible states of the world, where the decisions have to be made. The lattice model results converge to those of the Black-Scholes formula, as the lattice is divided into shorter and shorter steps. But in many real cases the decisions are, or even must be, taken at certain points of time – so that continuous valuation, as with the Black-Scholes formula is not realistic.

The key dilemma with the real options compared to stock options is in defining the volatility as the basis for the option modelling. Volatility is the central parameter in option valuation, describing the magnitude of the up and down movements of the underlying value. High volatility increases the maximal upside and downside that the value of the underlying asset can probably take, and thus the value of the related option. In the financial world, this parameter can be estimated from historical data. For real assets, however, estimating the volatility of project value is far more difficult, especially for projects that have not even started and might include novel technological and market aspects, as is the case in these studies. For financial options, the volatility can be seen as a constant due to their relatively short lives, whereas this assumption may turn out to be over simplistic for many real-world projects. Changes in volatility over time can be easily modelled when using the binomial lattice model, but not in the case of utilising an analytic formula.

The base line in the approach complies with the method presented by Copeland & Antikarov (2001). The key assumption there is called Marketed Asset Disclaimer (MAD). The MAD approach does not rely on the existence of a traded replicating portfolio as the case with option pricing. Instead, it uses the present value of the underlying risky asset (project) without flexibility (calculated using the DCF method) as if it were a marketed security. Then it relies on Paul Samuelson's theorem that properly anticipated prices (in a project's case the net present value) fluctuate randomly, as all the predictable trends are taken into consideration (Samuelson, 1965). The conclusion is drawn from this that the present value of the project behaves like stocks in the market, i.e. fluctuating with a volatility relating to the stochastic market changes. This, however, presumes that the present value of the project is properly valuated, also in relation to proper discounting of the project net cash flows according to their riskiness.

The MAD approach releases the problem of finding a true comparable or portfolio to define the proper volatility, risk and discount rate. The Capital Asset Pricing Model (CAPM) and the related firm's Weighted Average Cost of Capital (WACC) covers at least part of this problem, as it reflects the market valuation of the risk profile of the firm (Copeland et al. 2000). But it does not cover the risk differences between the projects inside the company. A new technology project contains normally much higher risk, but also greater opportunity, than the projects with stabile technology and sustainable services. This is the case when comparing, for instance, the mobile circuit-switched voice service and the potential new data services. When a project is in the context of continuous appearance of new solutions and technologies, the discount rate used inside the company to make the investment decisions must be rather high because of the high risk with many uncertainties. As some of the new technology projects in the company may fail, the others should bring the better outcome. This is reflected by a high discount rate in the calculations. The volatility, on the other hand, is estimated by Monte Carlo simulations of the model for project NPV as the input parameters (market demand) are statistically varied according to the best available assumptions of their probability distribution, as described below.

The studies thus estimate separately the applied discount rate (relating to risk and required return from the project) and the volatility that is used for the real option modelling. This is considered the right approach as even in stock markets the lack of significant correlation (either positive or negative) between expected returns and the volatility of the stock has been identified in several studies (Theodossiou & Lee 1995; Koulakiotis et al. 2006). The expected (mean) final results according to a fixed investment plan do not change due to the volatility considerations. The volatility affects only the option values realised in case of flexibility.

Normally, when modelling financial options, the present value of the asset (e.g. a stock) is separated from the investment related to acquiring the asset (the option's exercise price). In our case of "invest in UMTS technology deployment or not", the size of the investment (the "exercise price") depends on the state of the world, i.e. the model parameter values. For this reason it is not possible to model in the traditional way, where the strike (exercise) price is fixed beforehand. But the option value lies, in any case, in the ability to make the decision to invest or not at a later point of time, contrary to not having this ability at all. In the normal DFC case, the decision to invest is fixed before the start of the project. As in these kinds of projects the investment amount is dependent on the state of the world, the only way is to simulate the NPV that includes both the present value of the revenues and the needed investments to get them, and use it as the basis for ROA calculations.

The real options are usually modelled as geometric (multiplicative) lattices of present values, where the value of the PV is multiplied in each step by a factor higher than 1 (up movement) or lower than 1 (down movement) (Copeland & Antikarov 2001; Mun 2006b). This indicates that the value never goes below zero (like normal stock prices). But as modelling net present values that include the investments, they should be able to go below zero. Actually for this kind of communications technology projects even the expected present value of the project without investments can go negative in certain states of the demand due to the operational costs. It is suggested that an additive binomial lattice is the right way to model the project NPV development. For certain states of the world the modelling gives clearly negative values, and the option to discard the project in those situations is valuable.

The same kind of Monte Carlo simulations are run with Crystal Ball software as done with risk and sensitivity analyses, varying the service demand (usage), to get the mean expected results. These mean values turn out to be lower than the base line results calculated with the most likely parameter values, as the result distribution is biased towards the negative direction. This is related to the assumption that it is more probable to fall behind the predicted usage figures than to exceed them, because the network capacity would become a limiting factor in excess usage situations. This takes place either because of lacking incentive to upgrade it, or through the increased volume prices or volume gaps. But if the usage does not start up in the market, it is not so straightforward to boost it. This is reflected in the Minimum Extreme probability distribution used. Nevertheless, it is assumed that the mean NPV and other results derived from it describe the case better than the likeliest values, and the Real Option Analysis (ROA) is applied upon mean results.

The Monte Carlo simulation is run with yearly probability distribution of the service demand as input to get the annual variation of the NPV for the basis of the option valuation. For this method see, for instance, Boyle (1977). The simulation gives the annual standard deviation of the NPV for the modelled projects. This is interpreted as the volatility of the project, so that each year its expected NPV can increase or decrease according to this standard deviation, following the above-mentioned additive process.

The annual volatility is used to model the project value development only until the point of the launch decision. Then the decision is made, either to start the project or discard it. If also the deferral possibility is to be modelled, the new project NPV and new volatility should be calculated by new simulation of the project incomes and costs, as the project would lose the first year incomes and postpone first year costs. The postponed launch would affect also the following years' revenues and costs as the deployment and diffusion are time-consuming processes.

In the lattice presentation, the initial value of the underlying is denoted by V_0, for instance, the NPV of the UMTS network deployment, where discounted costs are deducted from the discounted revenues. If it is anyhow possible to deploy the EDGE capacity, which also has a positive value, the value of the UMTS project should be modelled as the difference between the NPV of UMTS deployment and the NPV of the plain EDGE project. As the decision can be done at different point for different types of areas, options are defined for each area type. The value of the underlying for the option to deploy UMTS is the value (NPV) of the UMTS case minus the NPV of the plain EDGE case. This underlying value changes as the state of the world changes, until the decision point to deploy UMTS to the particular area is reached. This kind of project setting, especially, requires the usage of the above-mentioned additive modelling, as the value can easily go negative if there is not enough demand for UMTS service requiring rollout of the expensive UMTS overlay network. The EDGE deployment would be more profitable in these situations.

We denote by u_V the amount that the value V goes up or down by each year. By denoting with p1, p2, .. the risk-neutral probabilities of the up movements, we can present the binomial lattice for the value of the underlying with two steps (Figure 21). For the lattice method with risk neutral valuation of options, see Cox et al. (1979) and Hull (2003).

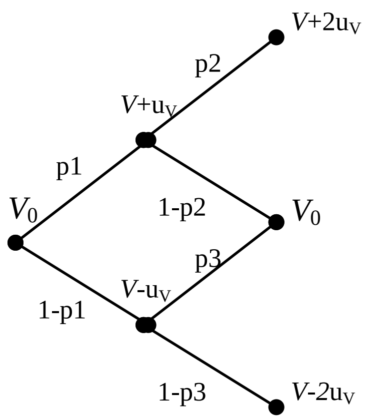


Figure 21: Binomial lattice for the value of the underlying with two steps

The volatility (standard deviation) of the V, and thus the steps up and down in the lattice, are calculated from the volatilities of the deployment projects. The volatility of a project is calculated from the effect of the market demand variation on the results that the techno-economic model gives for the deployment case. The figures on the nodes represent the evolution of the NPV of the network deployment, but in the end we exercise the option only if the value of the underlying is positive. In negative cases we do not exercise the option to deploy the technology (e.g. UMTS) and thus the value of the option is 0, although the value of the underlying is negative (i.e. the cost of the project would overrule the revenues).

With the up and down movements it is possible to calculate the development of the potential value of the underlying deployment project in the lattice (tree) up to the end nodes, and then, after putting the negative values to zeros, calculate backwards the option value. We utilise risk-neutral probabilities and a risk-free discount rate in the backward calculation of the option value; so that the value of the preceding node is the sum of the two consequent node values multiplied by their respective risk-neutral probabilities and discounted with the annual risk-free rate 3%.

The same arguments that are used to justify the application of net present value analysis (DCF) to "fixed" corporate investments can be used to justify the application of option value (or real options) to flexible corporate investments. The same source of input data for the valuation of DCF calculations, being in many case subjective assessments of the unsure model parameters, is appropriate also in ROA, but the dimension of flexibility in decision-making is added.

4. BUSINESS SCENARIOS

4.1 UMTS/WLAN business case

[Publication 1: Harno, J. (2004b). 3G Business Prospects - Analysis of Western European UMTS Markets. Proc. 1st International Symposium on Wireless Communication Systems (ISWCS). Mauritius, September 20-22, 5 pages.

Publication 2: Olsen, B. T., Katsianis, D., Dimitris D., Stordahl, K., Harno, J., Elnegaard, N. K., Welling, I., Loizillon, F., Monath T., Cadro P. (2006). Technoeconomic Evaluation of the Major Telecommunication Investment Options for European Players. *IEEE Network*, Vol. 20, no. 4, July/August, pp. 6-15.]

4.1.1 Background

In the years of the study, the telecommunications business field was turbulent, as waiting for the advent of the lingering third generation era. In the beginning of the 2000s, the mobile communications hype was at its highest. In Europe, the UMTS license auctions were running in UK and Germany during the spring and summer of the year 2000. The result was very high license fees, which were immediately followed by the downturn of the worldwide telecommunications sector.

Severe miscalculations by some business actors took place leading to loss of huge amounts of invested money. The consortia of Telefonica and Sonera, mobile operator Quam, as well as MobilCom AG failed in Germany, where the license fees were the highest - around 7.6B$/8.3B€ per each of the six licensees.

During the license bids it was difficult to see the reality through the mist of the hype of the mobile revolution going to change modern life. Nonetheless, a solid analysis of the market actors and their positions, as well as the costs and time schedules for building the networks - and especially developing, marketing and provisioning the new services - could have led to more reasonable expectations.

The problem is not only the lack of information concerning the future. It is also a question of methods and tools to model the different possible scenarios with a coherent view of the whole. The model should cover all aspects of the business at practical level of granulation, so that changing of, for instance, a demand or availability related parameter will be reflected in all respective costs and revenues. The model should also be adjusted to the total economic development taking into account, for instance, the limits set by the distribution of the total household spending in the market. In the most developed approach, the modelling would cover all the different actors in the market, but the needed relations and competitor actions are very challenging to model. In any case, even by running single-operator models for different scenarios, it is possible to give good advice in identifying the opportunities and threats, as well as the right strategies for different market conditions.

The emerging 3G (Third Generation Mobile System) business was in an ambivalent state. There was still uncertainty about which market segments would take the head, which services would be the most important and how high the spending on those might rise. New technologies had followed each other faster than have been possible to adopt, but new innovations have come true only after the functional infrastructure is in place and easy to use end-user services with practical value are available. Concerning 3G, the additional question for the actors was: how much the old platforms should be developed and/or "milked" compared to immediately stake on the 3G launch.

Another factor in the mobile business was the uncertainty about availability of adequate equipment, especially the end-user devices in the mass-production stage, with lucrative characteristics and functionality for a reasonable price. The operators' role was important in this context by provisioning and subsidising devices.

In the studied situation, it was not only question of the subsequent mobile communications platforms and generations, but the convergence happening in the communications field bringing in competition from new frontiers. Especially WLAN (Wireless Local Area Network) was seen much as a competing technology for cellular 3G networks. Here again, it was challenging to assess the future competitiveness or complementarity of this technology stream in relation to the 3G UMTS operator market position.

Regulators, as looking after the economic wealth of the society at large, acted in a significant and disputed role in the 3G play, either as introducing spectrum license auctions and gathering large amounts of money, or by "beauty contests" with usually strict requirements for the deployment of the infrastructure. These measures led to controversies on regulatory conditions for network rollout schedules, infrastructure sharing, bandwidth trading, license trading, and co-operation with Mobile Virtual Network Operators (MVNOs). The industry, especially in Europe, was afraid that increasing regulatory intervention will restrict free pricing and cost sharing, thus making the launch of 3G services more challenging than it already was in this economic situation.

Björkdahl & Bohlin (2003) provide top-down studies on some 3G operator cases in European high 3G licence cost countries. As investigating the additional revenue per user (ARPU) that the 3G subscriber should generate against the investment costs needed (above all the high 3G licence cost), they end up to the conclusion that the business case would probably not be profitable. It would need subsidisation from 2G-type services or from other markets, indicating a regulatory concern. These studies differ from the thesis studies in using a top-down approach (utilising general ARPU and cost figures) contrary to the bottom-up approach (looking at specific services and related costs) in this thesis. Also the point of view at the case differs between the approaches, which can explain the deviating outcomes on profitability: Björkdahl & Bohlin look at 3G as a separate business case overlaying the 2G provisioning, just as in the thesis study, but they take the 2G service continuing as it was when the 3G was launched, generating the same revenues (ARPU) from the full subscriber base, and that revenue is not counted to the 3G business case. They thus concentrate on the added value from the 3G. Contrary to that, in the thesis study, when a subscriber migrates to the 3G (terminal and network usage) its revenue is counted to the 3G business case instead of 2G. This thinking is based on the view that mobile generations follow each other like waves so that they have their cashing periods that peak at certain point of time and then degrade. This curve is assumed also for the 2G business, so that if the operator does not provide 3G as the others do and there is demand for 3G service, it will start losing customers. Thus competition forces to some cannibalisation of the revenues from the previous technology generation.

Björkdahl et al. (2004) investigates also the WLAN technology as a case of "4G immediate vision", in a stand-alone business case and as complementary service for wide area 3G deployment. They demonstrate in accordance to the results in this thesis that the stand-alone case for public WLAN is unlikely to prove a sustainable business model at least in the short term, in spite of the free spectrum and relatively low investment costs compared to 3G. They indicate that the fragmented structure of the WLAN market and network, with inferior availability and usability factors would make it fail in competition with 3G solutions. They note, however, in line with the thesis study again, that even if public WLAN fails to show profitability as a stand-alone business case, and cannot be seen as a substitute to 3G, it may prove to be of high strategic value as a niche and an important source of competitive differentiation for 2G/3G operators. They also point out that WLAN is probably just the first step in an emerging technological trajectory from the computer industry entering the telecommunications industry, and that WiMAX following in row may eventually reshape the structure of the telecommunications industry and its dynamics. This viewpoint relates to the second business scenario modelling in this thesis: "Technology competition in 3G and beyond service provisioning" (Chapter 4.2).

To complement the focused technology and market studies and the research intended in the first place to serve the European policy making, a long haul model with extensive technology and business modelling was needed primarily to support for justified investment strategies in the industry. To cater for this need, groundbreaking research in telecommunications techno-economics field was performed by a series of EU funded projects, for this case the TONIC project. It pursued full bottom-up modelling of the operator case for 3G, including both revenues (per customer and service) and costs (each related CAPEX and OPEX item). Due to the extent of this kind of undertaking, requiring access to knowledge of several business and technology domains, there have not been other public projects with the same kind of scope. The thesis author was strongly involved in this work, especially relating to the mobile business cases. Based on this, several journal, book and conference articles about the techno-economic analysis of early 3G business cases have been published (the first two are included into the thesis: Harno 2004a; Olsen et al. 2006; Harno 2002; Varoutas et al. 2002a; Loizillon et al. 2002; Harno et al. 2003; Welling et al. 2003; Varoutas et al. 2003; Welling, I. & Harno, J. 2004; Harno 2004b; Harno 2005; and MVNO case related: Varoutas et al. 2002b; Varoutas et al. 2002c; Varoutas et al. 2002d; Varoutas et al. 2002e; Varoutas et al. 2002f).

4.1.2 Case modelling

All the main business aspects introduced above have been in the focus of the study. An "incumbent" operator, with a 2G infrastructure and customer base already there, and possessing a UMTS license, has been selected as the focus for the main study case. WLAN is an option for the operator to supplement its infrastructure and service portfolio. In addition, the needs and potential benefits by infrastructure sharing are analysed. The MVNO business case and discussion about the impacts of admitting an MVNO into the network, from the MNO's perspective, is included too.

The modelling aims at obtaining a holistic view that combines service classification, demand development estimation, technology deployment, cost modelling, pricing, and revenue forecasts based on the methods and data sources presented in the techno-economic method description in Chapter 3. In this chapter, the case specific parameters are presented only in brief.

In the case studies, the fundamental question is: Is it possible to recover from the heavy investments first into UMTS licenses and then into network rollout, marketing etc., and if so, what would be the net result and pay-back period? Thus the UMTS project has been separated from the 2G business to get a focused view on the effects of UMTS demand, rollout and service provisioning on the costs and revenues of the operator. However, the underlying 2G/2.5G network, providing, for instance, antenna site infrastructure and seamless handovers in case of limited WCDMA (Wideband Code Division Multiple Access) coverage, has been assumed. But only the traffic coming through UMTS network (and UMTS devices) is calculated for the business case.

From the operator business point of view, the UMTS usage, is in a way, cannibalising the 2G revenues, but on the other hand in the end UMTS provides the most cost efficient way to build the capacity for increasing need, and in many cases the UMTS frequencies are the only possibility as the lower bands are already in full use during the peak hours. The separated approach is justified also because UMTS is seen to be the only way to keep the advanced customers in the beginning, and others in the end, so that revenue from many of those customers would be, nevertheless, lost to the competitor without the UMTS project. This thinking was probably also behind the enormous license auction bids by the dominant actors and some well-off challengers.

In this study, the 3G UMTS case is examined within a quite large time span (years 2002 – 2011). This reflects the fact that UMTS is a long haul project, as the licenses are in most cases for 20 years. On the other hand, ten years describe reasonably well the 3G window of opportunity for the operator, as the pace of emerging new technologies should be taken into account. The study addresses also the current hot topic of 3G or UMTS delay and its effects. The modelling allows the simulation of the delay in service launch or take-up, with related risk and sensitivity analyses.

If the general delay, observed in the 3G launches, is interpreted as technology, applications, and service immaturity that cause lack of supply and demand for 3G, then the latent potential for the new 3G frequency band and services is only waiting for the right time to break out. This probably relates to the same immaturity that has eroded the WAP (Wireless Applications Protocol) and GPRS (General Packet Radio Service) cases thus far. It seems that repeatedly the challenges have been first underestimated. Another possibility is that the demand is really not as high as anticipated. This assumption leads to different economic scenarios, which it is possible to cope with using the model.

4.1.2.1 UMTS diffusion estimation

The basic demand forecasts were performed for the Western European market. The demand for 3G services is based on the overall mobile penetration, so the study is started with total mobile subscriber penetration forecasts (based essentially on 2nd generation systems such as GSM today). After that it was focused on forecasts for the penetration rates for the following mobile generations:

- 2.5G – HSCSD, GPRS
- 3G – UMTS
- 3.5G – meaning here 3G and WLAN systems as a combined solution

Based on the assumptions for the evolution of the total subscriber penetration, combined with assumptions regarding each of the mobile systems, we have estimated the default penetration for the four different mobile generations utilising the logistic model approach described in the method chapter. These penetrations are shown in Figure 22.

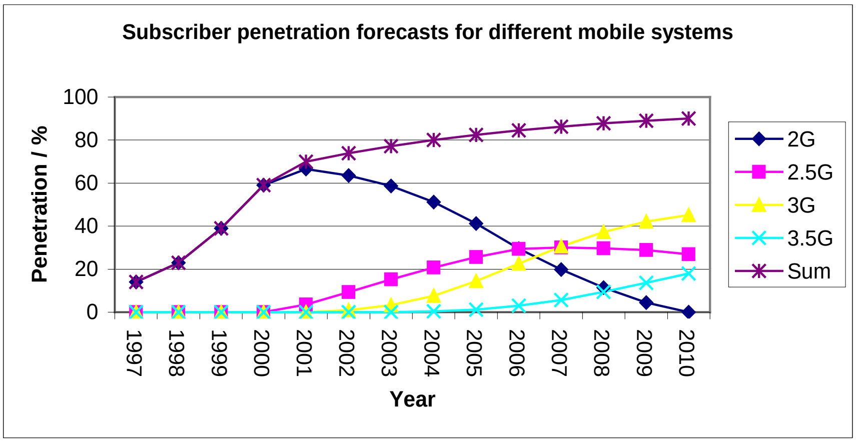


Figure 22: Subscriber penetration forecasts for different mobile systems for Western Europe (Publication 1)

4.1.2.2 Service classification

The analysis of the impact of different future 3G services is challenging. The usage estimations are based on the service potential of the new technologies. All of the possible services are not yet foreseen, not to even mention the "killer applications". For this reason the selected approach has been to abandon individual service demand forecasts and to aggregate services into classes that can support capacity calculations and tariffing and thus revenue potential of the forthcoming 3G services.

First it was taken into account the four Quality of Service (QoS) classes in the 3GPP specifications:

- Conversational
- Streaming
- Interactive
- Background

The last two are mainly looked as combined (int/backgr.), since the requirements for the network are more alike compared to others. Each of these is further classified according to the bandwidth utilisation to:

- Narrowband: with int/backgr. peak bit rate 32 kbit/s
- Wideband: with int/backgr. peak bit rate 384 kbit/s
- Broadband: with int/backgr. peak bit rate > 2 Mbit/s

In this classification the Broadband (BB) class was initially available only when the WLAN access was possible. Within the Conversational Narrowband (NB) and Wideband (WB) classes, there was made an additional distinction between the Circuit Switched (CS) and Packet Switched (PS) mode. Other classes are based purely on a Packet Switched carrier. The utilised service classification is described in more detail in Section 3.3.

The estimated usage figures of the services within each service class form the basis for the capacity demand calculations and, together with pricing forecasts, for ARPU estimations. The usage forecasts are based on the foreseen service portfolio in each service class. Usage is first estimated as the usage (session) time per day in each class. This amount is then multiplied with the mean bandwidth usage during the session. Busy hour and Erlang calculations are then performed to get the peak capacity requirements. This procedure was described in Chapter 3, Figure 11.

4.1.2.3 Pricing

Compared to the old era of mainly voice and then SMS, the new mobile data services bring many new possibilities in charging policy. Variety within tariffing schemes is broad, starting from a pure monthly flat rate or transmission volume based tariffs, and continuing to different kinds of packages, based on bit rates, minutes, packet amount, Mbytes, subscribed or used services, content, etc. The applied pricing policy in this study is cost based, relating to the required capacity build-out. The principles for this are presented in Chapter 3.

4.1.2.4 ARPU projections

The UMTS revenues are dependent on the network rollout, as the 3G usage is calculated only if the user is in the coverage area of the UMTS network. Otherwise the service is not available and the demand is not fulfilled or the usage goes seamlessly to the GSM/GPRS network, the revenue from which is not counted.

The ARPU figures are usually counted plainly as the revenues divided by the amount of subscribers. This might cause some confusion in the situation where the operator provides several systems (2G and 3G) simultaneously as we want to separate the revenues from subscribers of different systems. According to knowledge from previous mobile generations the first migrates are clearly spending more than the latecomers. An oppositely affecting factor is that, in the beginning, much of the usage and revenue goes to the 2G network as the 3G coverage is lacking. UMTS users' ARPU rises quite high in the beginning, when the rollout has reached a good coverage, and the high-end users have migrated in, but then turns into degradation due to tariff erosion and incoming lower usage customers.

The model focuses on the UMTS revenues, but for comparison with the commonly presented total subscriber base ARPU figures, also the revenue calculation for all mobile subscribers is presented. This ARPU pattern is presented in Figure 23, where there can be seen a maximum monthly ARPU (about 50 €), which is reached in the later period, as the bulk of the customer base moves to UMTS. This reflects the basic assumption that UMTS brings in new types of services and usage, which shifts the consumer (and corporate) spending towards (mobile) communications consumption during the study period. This is assumed to be in line with the average consumer spending on communications that was increasing strongly and constantly, with 50% growth during the 2G (GSM) diffusion phase in the last decade, especially in the latter half of it, as can be seen in Figure 12, presented in Chapter 3.

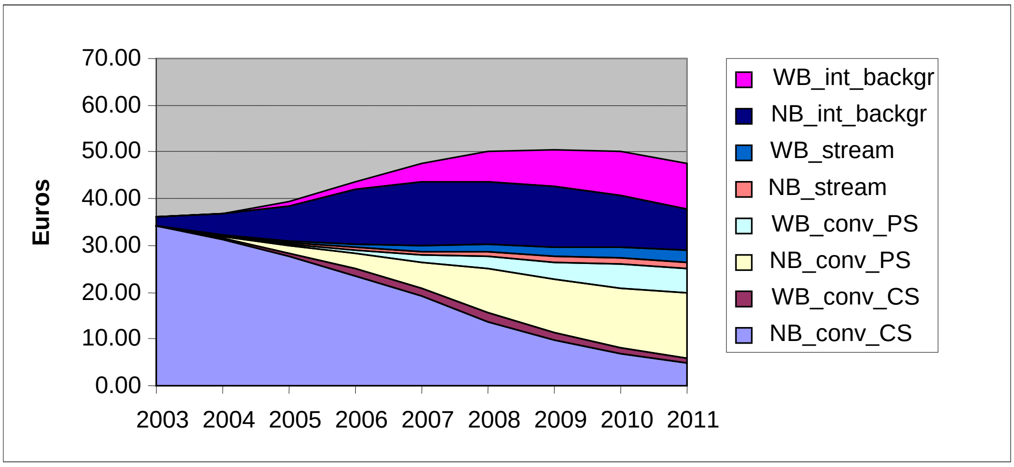


Figure 23: Subscriber Breakdown of monthly ARPU of all mobile subscribers (without WLAN) (Publication 1)

4.1.2.5 Required investments and operating costs

The required investments and operating costs are calculated according to the modelling and technology specific data as presented in Chapter 3.

4.1.3 Main analysis results

Six basic scenarios have been investigated, supplemented with risk analyses and additional studies on effects by, for example, infrastructure sharing and MVNO co-operation. All the scenarios start the network deployment in year 2002 from the dense urban areas and continue towards the less populated areas. For the country characteristics please refer to the method description in Chapter 3. The full rollout to rural areas takes ten years in the Large country and the Small country with slow roll out scenarios, but is completed in three years in the Small country with the fast roll out case. Results for every defined case are as follows:

Table 14: Summary of main results from evaluated basic scenarios

Scenarios	NPV (M€)	IRR	Pay Back Period (years)
1 Small Country with slow roll-out, without WLAN provisioning	635	39%	6.3
2 Small Country with slow roll-out, providing WLAN service	690	39%	6.4
3 Small Country with fast roll-out	98	12%	8.1
4 Large Country with high license fee, not providing WLAN service	5 639	19%	7.1
5 Large Country with high license fee, providing WLAN service	6 703	20%	7.0
6 Large Country with lower license fee	9 754	40%	5.9

The study shows that the UMTS business cases can be positive for operators with a substantial market share (~30%) in both large and small European countries. This is contrary to the depressing view dominating the industry analysts' reports today. The payback periods are generally around 7 years, which is not too long considered against the magnitude of the project.

For the large country case, a license cost of 6 billion euros and for the Small country case a license cost of 6 million euros has been applied for the Large country case, slightly under the extreme license costs in UK and Germany. For a Small country a fee of 6 million euros has been applied, an amount being more related to the situation of Nordic countries (small countries in terms of population). The impact of high license fee does not threaten any large country business case, but a lower fee (20% of high license fee = 1.2 billion) would gain one year in term of payback period, and clearly stronger results. Especially for sparsely populated small country cases, the UMTS rollout benefits substantially from the investigated infrastructure sharing approach, and in the case of extremely strict network rollout obligations, the sharing is inevitable to secure the case economically.

Non-discounted investments in the Large country case for the whole study range are not more than 1.9 B€, partly due to a long rollout period and quite rapidly degrading equipment prices. The investments consist of base stations (45%), site build out (20%, with one third of the sites new), switching, routing and control centres (23%) and new billing systems and other OSS and software (11%). The backhaul and transport is modelled as leased line costs thus within Running Costs. See

Figure 24 below.

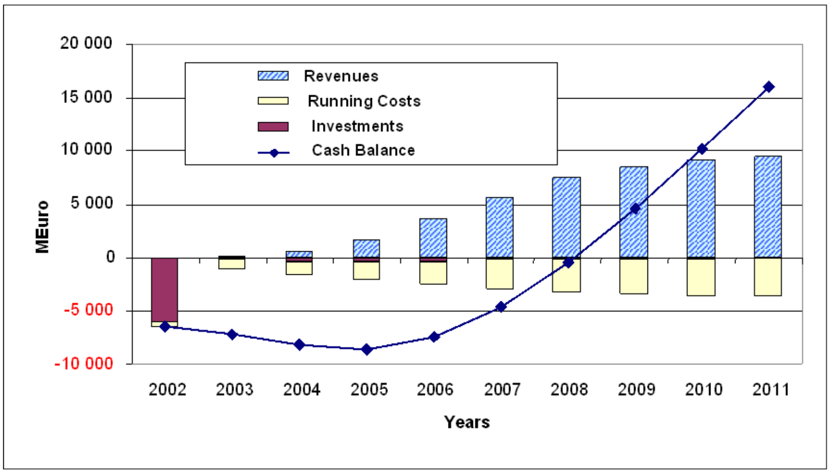


Figure 24: Economics of the Large country incumbent UMTS business case (Publication 1)

Our modelling indicates that the existing 2G market share is not a mandatory requirement for success of the large country business case, although the existing infrastructure gives a considerable benefit. Differentiation with better service by UMTS is the opportunity for the challenger. It can be demonstrated that a high amount of capital resources are needed to survive the required marketing and network build out costs in the early period. Without early roll-out, service provisioning and marketing, it is not possible to attract the early adopters. The scenario for the challenger with high marketing charges (included in the running costs), capturing gradually market share as high-end customers and then widening customer base migrate to UMTS, is presented in Figure 25. The NPV for this scenario is 4.4 B€ and the IRR 16% (Harno 2004a).

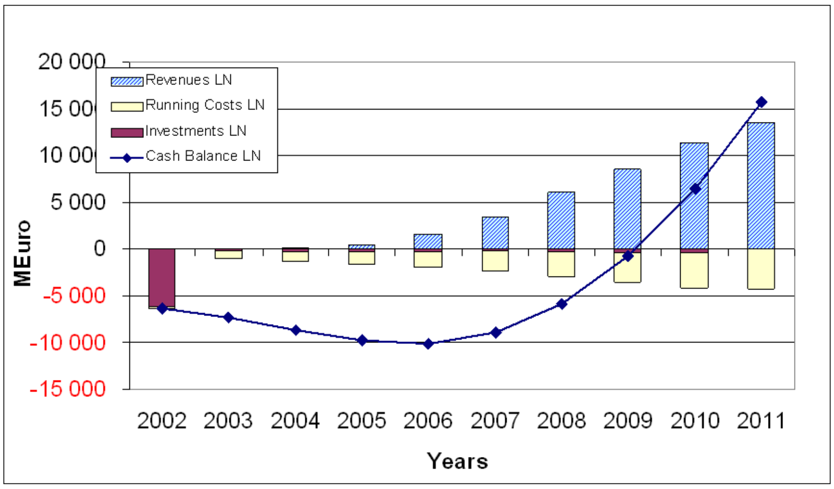


Figure 25: Economics of the Large country challenger UMTS business case (Publication 1)

The first assumption is that the Small country business case follows a fast rollout schedule. It reflects the heavy regulatory requirements to cover virtually the whole country by the end of the year 2004, as, for example, in the original license terms of Sweden. On the other hand, the Small country case, as representing the common “beauty contest” auction scheme, has practically no license fee.

With this very fast rollout schedule the case shows only a slightly positive net result in the long run, with NPV 98 M€ and IRR 12 %. See Figure 26 below.

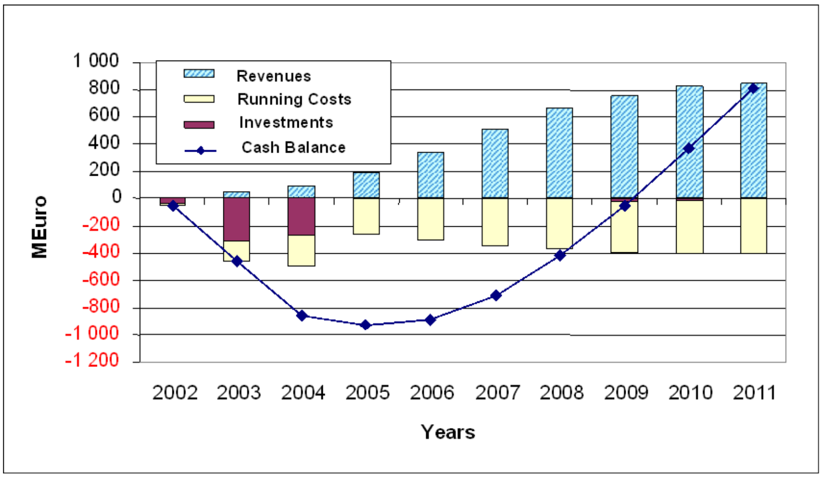


Figure 26: Economics of the Small country business case with fast rollout (Publication 1)

This indicates quite a vulnerable business case and it turned out that these kinds of tight regulatory requirements are alleviated in the situation where UMTS launches tended to be postponed. The slower rollout business case shows clearly higher and more robust results.

4.1.3.1 UMTS delay considerations

In the basic cases the UMTS launch of the operator was scheduled in the year 2003. The model illustrates also the effect of delay on the operator’s economic end results. Figure 27 depicts the

Large country NPV change as the UMTS launch is postponed. The assumption there is that the demand (or penetration) curve shifts forward according to the delay. Also the UMTS demand continues the respective interval further than in the basic case. As the investments, especially the high license fee, are already made, the profitability of the case erodes as the revenues are postponed.

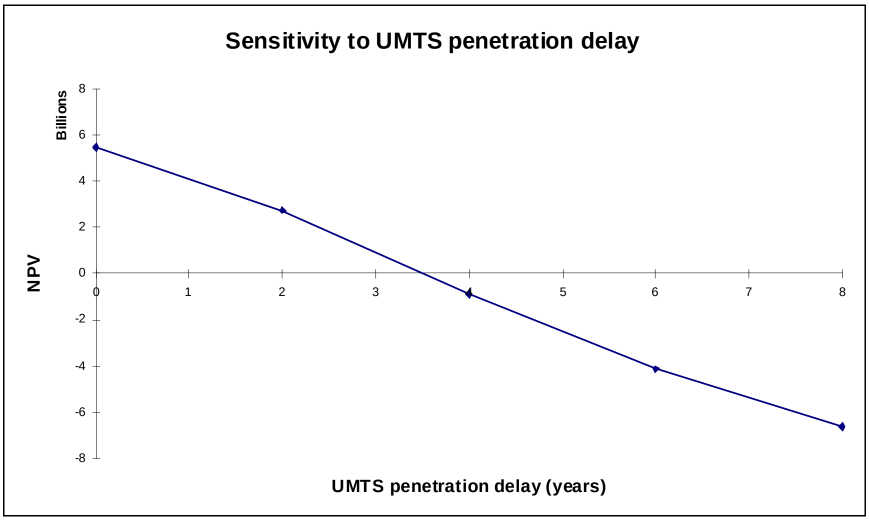


Figure 27: Economics Large country NPV as a function of delay (prolonged lifecycle) (Publication 1)

If the assumptions are otherwise the same, but it is supposed that the UMTS lifecycle ends like in the basic case, for example, due to new emerging technologies, the results drop more dramatically: in one year NPV drops from 5.6 B€ to 3.2 B€, and the IRR from 18.8% to 15.3%, and shortly after the second year the NPV goes negative.

The postponement of investments (network rollout) with the same time shift does not help, but rather make the case worse: with a one year shift also in the rollout schedule gives NPV of 2.4 B€ and IRR of 14.1%. This reflects the fact that even though the launch might be postponed for some market or technology reasons, the recovery from the investments and utilisation of the limited technology lifecycle demands relatively rapid network deployment.

4.1.3.2 UMTS pricing considerations

The tariff level in the model for Interactive/Background service starts from 1.5 €/MB in 2002, after which the tariff erosion has applied. Currently the GPRS and UMTS tariffs are generally quite complicated, with many alternative pricing plans. Typically, they include a selectable quota of megabytes for fixed monthly fee, plus a respective MB price for the additional traffic. Depending on the distribution of the customer base into different pricing plans, and their real usage amounts, the average MB tariff may vary quite much. This is affected also by the marketing and service offering by the operator.

The economic effects of lower MB prices with higher traffic can be investigated, while keeping the ARPU figures constant: If the MB price halves at the same time as the traffic doubles, the Large country NPV drops from 5.6 B€ to 4.7 B€, and the IRR from 18.8% to 17.4%. This is not a very dramatic reduction in profits for a doubled capacity demand, reflecting the fact that network build-out costs are relatively low for the needed extra capacity.

4.1.3.3 WLAN effect on UMTS case

The WLAN technology was investigated as a complementing technology for UMTS, providing high bandwidth services on hot spot sites of limited number and coverage. With reasonably modest deployment (about 3 500 sites with some 10 000 access points in the Large country) the effect on the total business case was identified not to be dramatic, but nevertheless increasing the NPV from 5.6 B€ to 6.7 B€, and the IRR from 18.8% to 20%.

The effect of WLAN was identified to be at least two-fold: it may cannibalise some UMTS revenues due to lower MB tariffs, but, on the other hand, the WLAN availability in certain situations may feed the usage of wideband UMTS services generally, provided that the roaming and service inter-working aspects are in place. If the highest capacity consumption is directed to WLAN hot spots areas, also the UMTS rollout costs are reduced.

It is probable that no single operator can cover all hot spots of interest (even due to access rights to the area). In any case, with intelligent roaming agreements it seems that the complementary nature of WLAN can be sustained by the UMTS operators in Europe.

4.1.3.4 Infrastructure sharing and MVNO considerations

Infrastructure sharing was identified to be almost obligatory in certain sparsely populated countries, especially if the coverage requirements were high. For the Small country case with fast rollout, already 20% sharing of capacity, and thus build-out costs, improves the case dramatically: NPV increases from 97 M€ to 269 M€ and IRR from 12 % to 17%. For the Large country the improvement is comparatively small, as the investments are mainly capacity driven.
An alternative strategy for infrastructure sharing may be to sell the excess capacity to an MVNO. The MVNO case in the 3G era has been demonstrated to be potentially profitable both in large and small countries. The MVNO entry to 3G business represents a profitable option also for the MNO. Furthermore, as new technologies and new services appear and the m-commerce, location-based commerce and short-range commerce are continuously developed, the MVNO for 3G can become a viable win-win situation for all business actors. An initial position in the 2G business of the MVNO is, however, seen as an important success factor in the emerging 3G market. The business case for new MVNO without any brand name does not look lucrative. Marketing and entry costs in general can be a burden for a potential MVNO, but this can be overcome by a high brand firm or an already operating company. The results also show that for an MVNO it is potentially very profitable if it can expand its services by providing broadband services via WLAN.

4.1.3.5 Identified threats inherent to the business cases

The techno-economic modelling of the Publications 1 and 2 demonstrates how the UMTS launch will substantially increase the revenues from the early adopters migrating to the new system with richer service portfolio. These growing revenues will be postponed in cases of a delayed UMTS launch and take-up, eroding the UMTS case. On the other hand, the subsequent 4G-technology generation is putting pressure, as a considerable delay may shorten the lifecycle of the UTMS and especially its “cash cow” period.

As the delay can be tackled by concrete measures, the general recommendation in Publication 2 for actors in the markets investigated is not to postpone the necessary investments and development for full UMTS service provisioning. Not only the telecommunications operators should be in charge, but the value chain and partnering modes are richer and more vital than with the much narrower 2G approach. The take-up of new services will happen only if they are developed and provided in an attractive way. UMTS currently offers the best and most efficient platform for the totality of 3G services (enhanced video calls, fast Internet access and file transfer etc.), and is the only possible one for many of them. When the full breakthrough of 3G happens, those actors that have already a successful entry in the market will benefit most.

It was claimed that the rise of public access WLANs will have large impact on 3G businesses by cannibalising potential 3G revenues. This indicates that revenues diverted away from 3G networks by WLAN type stand-alone networks will be a big risk, since the latter are supposed to be much more cost effective. Publications 1 and 2 suggest that this view does not apply to the main Western European business actors, and that 3G and WLAN are essentially complementary within a total mobile data services portfolio. WLAN is at least in the beginning representing only one service category of 3G service provision, namely Mobile Intranet/Extranet Access. This category is especially suitable for workers on the move who have a need to access corporate intranets and the Internet remotely. Such workers are also likely to be the main users of public WLAN services. By combining a public WLAN service with their 3G services, operators will be able to offer a seamless mobile data communications solution for the business user. Results show that WLAN revenues are small compared to the whole 3G revenues, so the economic figures in most cases are not significantly influenced. The WLAN business as such is seen as small and not competing with the wide area mobile access.

4.1.4 Assessment of UMTS/WLAN business case studies

The motivation behind this business case analysis was to help in evaluating whether very large-scale UMTS investment projects would pay back. This was a vital question for the operators in Western-Europe who had acquired the UMTS licenses. But answering to this question depends on the strategy and business architecture that the market actors will deploy. Therefore, the applied techno-economic modelling aimed to

1. figure out the market development with the most eligible business architectures and estimate the revenue potential of the respective business cases
2. give a reliable estimate of the respective costs, to be able to calculate value of the case
3. analyse the possible threats

How well these goals were achieved will be assessed in the following subsections.

4.1.4.1 Estimation of revenue potential

The revenue potential consists of the potential in user diffusion, on the one hand, and of the revenue potential per service user, on the other hand.

Potential in UMTS diffusion

The diffusion forecasts for different mobile technology generations played an important role for the basis of revenue forecasts. The forecasts were made to estimate the development for a dominant operator actively promoting UMTS for its customers and deploying its network.

When comparing the diffusion curves (see Figure 22 above) of the study with the realised figures, attention should be paid first to some critical conceptual definitions that tend to cause confusion. In the modelling, it was consciously decided to do it based on subscriber amounts instead of subscription amounts, although the latter figures are much more widely used. The wide usage of subscription amounts derives most probably from the fact that the operators have in their data sources readily available and they gladly give out the amount of subscriptions. The subscriber amount on the contrary is in many cases hard to achieve, as the connection of several subscriptions to the same subscriber is hard and might be even impossible in the case of subscriptions to different operators.

In the studies subscriber is defined as the actual user of a mobile device, not depending if he has made the contract or paying the bill, or not. The contract might be done by the employer or, for example, parents of a child. However, the subscriber amount can be estimated and some telecommunications regulators organise also questionnaire studies about the mobile telephony user (i.e. subscriber) base. For example, according to the study by the Finnish Communications Regulatory Authority (FICORA 2008), in the year 2008, 98 percent of the 15-79 year old respondents had a mobile phone in their use. It should be noted however that in Finland a mobile phone is very common for children already from the age of 7. Moreover, the saturation level for penetration, which is important in our diffusion model, is well definable for subscribers being always under 100%, but there is no general upper limit when predicting this level for subscriptions. The latest statistics (II/08-I/09) from Finland also tell that even though the amount of subscriptions increased by 8%, the amount of calls decreased slightly.

The reason to estimate the subscriber/user amount is that it gives much better possibilities to forecast the service usage amounts and thus traffic, costs and revenues. Usage is a quantity that relates to users, their habits and experience, without dependency on the amount of subscriptions the user might have. In many countries people can have simultaneously many latent subscriptions for different reasons, for example, prepaid SIM cards with no actual usage. Also in case of one device for business usage and other for private, the generated total usage is much analogous to that of those using only one device for both purposes. In this kind of case, nevertheless, the business user profile should be used for the amount of usage. In our modelling, the segmentation was an important part so it is needed to estimate the amount of people in different segments too.

The diffusion (penetration) curves in Figure 22 seem to go somewhat faster up for the advanced 3G and 3.5G technologies, compared to the generally realised figures. Referring to what was said above, the distortions caused by deviating definitions have to be corrected and interpretation of the figures made clear. The first point is that the commonly presented penetration figures are country averages, but we are using in our modelling figures for a particular type of operators, assumed to make efforts to promote UMTS diffusion in their networks and subscriber base. The other one relates to the difference between subscribers and subscriptions. The third potential source of confusion is that not all 3G devices are even in the statistics compiled for the 3G penetration, as some laptops or related equipment utilising 3G radio may often be included in the fixed network business and thus not seen in the operators' 3G penetration statistics. However, as modelling the usage of the network and service resources, all equipment utilising the resources needs to be taken into account.

According to Mobile Communications Europe (2008–2009), the proportion of 3G subscriptions out of all mobile subscriptions was, at the end of 2008, highest in Europe in Portugal (36.6 %). A percentage level over 30% was reached also by Spain (33.5 %), Sweden (33.4 %), Italy (31.9 %) and Austria (31.4 %). The next was Finland where the proportion of 3G subscriptions was 29.5 %, an increase from previous year of 7.9 percentage points. At the same time, the subscription penetrations were: Portugal (137.2 %), Spain (115.5 %), Sweden (125.6 %), Italy (147.7 %), Austria (125.8 %) and Finland (130.5 %).

Finland is one of the Western-European countries where subscriber penetration is the highest. According to the latest statistics (FICORA 2008), as referred to above, the subscriber (user) penetration was 98% in the age group of 15-79 years old. According to the Finnish census, about 8% of the population is under the age of 6.5. For an upper limit it can be assumed that, as children start the school in Finland at the average age of 6.5 and most of the children get their first phone then, there are about 10% (the 2% of the age group of 15-79 years plus 8% consisting of the youngest children and oldest people) of the population who are not using a mobile phone. This is a rough upper limit that probably holds currently in all Western-European countries, most of which having clearly lower penetration. This is also the value given by our diffusion model for the saturation of the mobile subscriber penetration.

It can be assumed that even though people can have several subscriptions, i.e. SIM cards in their use, still very few have several 3G handsets, most of the additional subscriptions being to 2G. If now assumed that the upper limit of subscriber penetration is 90% and that 3G subscriptions equal 3G subscribers, as transposing the above 3G proportions of subscriptions to 3G subscriber penetrations, the following figures are obtained: Portugal (36.6 %*137.2%/90%=55.8 %), Spain (33.5 %*115.5 %/90%= 43.0 %), Sweden (33.4 %*125.6 %/90%= 46.6 %), Italy (31.9 %*147.7 %/90%= 52.4 %), Austria (31.4 %*125.8 %/90%= 43.9 %) and Finland (29.5 %*130.5 %/90%= 42.8 %).

As categorising the subscribers according to the highest technology used, it can be seen as comparing these values to Figure 22, where the 3G + 3.5G penetration is slightly less than 52% at the end of 2008, that they mach quite well with the most advanced Western-European country averages. There are, nevertheless, large European countries clearly lacking behind these figures, like UK (33.6 %) Germany (23.5 %) and France (18.1 %), according to the figures calculated above. But as already mentioned the modelling approach in this thesis aims to build the business case for an active promoter of UMTS and advanced services.

We have still to correct or complement these figures, as the laptop usage of mobile broadband is not in these figures. For example, in Finland the UMTS access through laptops, which are connected via USB modems, data cards or have embedded mobile modules, are categorised under broadband access (like ADSL) and is not included in the above 3G mobile subscriptions. That access type emerged in Finland mainly in the second half of the year 2007 and since then has grown very rapidly, starting to reduce the amount of ADSL connections. At the end of the first half of 2009, there were already over 660 000 subscriptions, more than double the figure of a year before, meaning a 14% penetration in the population. The laptop UMTS connection, usually mostly utilising HSDPA for higher bit rates, has actually largely taken the place of the public WLAN access, which was coined 3.5G in the study, and generates the bulk of the very rapidly growing 3G data traffic. Its diffusion seems to follow the penetration forecasts and usage patterns for the 3.5G in our model. Taking this into account too, increases the sum of the advanced mobile penetrations for the European countries even higher. However, it should be noticed that many laptop 3G users may be the same as the 3G subscribers counted above. On the other hand, one mobile broadband subscription, for example, at home may have several users. All these factors have to be taken into account in the modelling of the business approach, service usage and traffic.

The potential for high UMTS service penetration has probably been best promoted by the Hutchison Whampoa 3G (brand name “3”), which has based its business solely on the 3G network, providing roaming to rented 2G capacity, where they have not yet 3G network coverage. It was the main contributor to the launch of the UMTS in Europe, in the situation where other actors were waiting and hesitating to invest in the downturn after the IT bubble burst in 2001, shortly after the UMTS auctions. Its business plan of a start-up for pure 3G service promotion and the precondition of extensive financial resources were crucial to carry out the long haul project. The suggestion of the study model about the cost of the delay in harvesting from the big investments in UMTS was emphasised in H3G’s business case, as the “cannibalisation” of the older generation revenues was not distorting its goal. However, the base case model in the study was not that of a start-up actor, but for an incumbent operator with considerable initial market share.

Revenue potential per user

For many other actors the delay in launch was realised, but it was not long, as in 2004 the widespread emergence of commercial 3G services took place in Europe. Nevertheless, the service demand suggested in our model has not been widely realised, at least the per user revenue (ARPU) levels suggested, for example, in Figure 23 turned out to be too optimistic compared to the general ARPU trend of the European operators during this decade. The decline of revenue from narrowband conversational service (mainly voice) is clear as forecasted also in the study, with the exception (which has no effect on the results) that the conversional data has not changed to packet-switched (PS) mode. This deviation derives from the development in the circuit-switched voice radio technology, which has improved its efficiency, so that in UMTS the benefit from switching voice to packet traffic has become negligible for the operators, giving either no incentives for handset vendors to market these features.

Although the Voice over IP (VoIP) could have provided considerable savings for the subscribers, especially in long distance calls and when calling abroad, it has not had a remarkable effect on the business case under study. This is because of the operators’ data (IP) traffic pricing and difficulties in utilising other connections than the own operator’s network, for example, WLAN access for VoIP calls with a mobile handset when on the move or abroad. For businesses having much international roaming this could have been a possibility to save costs, but the operators have been able to modify their charging to dampen down the emergence of notable alternative solutions in mobile telephony thus far.

The main dilemma is that the ARPU has been almost flat, in many cases even declining, instead of the growth suggested to come mainly from the interactive and background service classes. The revenue from data services has compensated for the decline in voice service, but the competition has driven the data transmission tariffs downwards and flat rate tariffs on a rather low level have been introduced by several actors. The data tariffs were still at quite a high level in 2006, as the flat rates were still quite rare in Europe, on the level of 60€ or more per month (OECD 2006), but at that time the user base was also low. In mid 2009, the cheapest flat rate 3G data packages are, for example, in Finland priced slightly under 10€ for max 256-512 kbps connections by the main operators. For 1 Mbps the monthly price typically doubles, and doubles again for 2 Mbps.

As interpreting the data about decreasing ARPU trends, the same notions have to be made that were made above in relation to subscriber penetration: As the ARPU is commonly calculated from revenues per subscription (inconsistently though, as its definition refers to Average Revenue Per User), the growing amount of subscriptions per user decreases the measured ARPU value although the average spending per user would stay at the same level. As noted earlier the subscription penetration could be even 147.7 % like in Italy, but the subscriber base less than 90%, transforming, for example, the 30€ monthly ARPU to about 50€, as calculated per subscriber. Also in USA, where the subscription penetration is still under 100%, the monthly revenues per subscription are still (in 2007) clearly on a higher average level than in Western-Europe (e.g. for Sprint even 64 USD, see OECD 2009).

The same way, the subscriber's spending relating to an additional (laptop) mobile broadband data subscription is not counted to her ARPU contribution, although it is part of her 3G usage. (The broadband 3G data access could be interpreted to replace the spending on WLAN BB access in the modelling.) Nevertheless, the fast growing trend in the proportion of household spending to communications that prevailed until the year 2000 and was the basis for our forecasts (see Figure 12), changed first to a lowering growth and then after the year 2004 to a decreasing trend, although the absolute amount of the disposable money continued to grow (OECD 2009). However, in some of the Western-European countries the high growth has continued, relating especially to mobile communications.

The development of many operators has been towards more or less a "bit-pipe" model, where the competition is in providing price competitive data connection to the Internet. In this case, the mobile operators are successfully rivalling even with fixed BB providers. This is a strong deviation from the business plan suggested in the study. Most of the operators have not been able to build the value networks needed for flourishing end-to-end mobile value added service business architecture. It is actually far more complicated than the straightforward infrastructure build out. The importance of investments in services, partnering and value chains were emphasised in the recommendations of the study and the results were based on this kind of approach (Publication 2, p. 12): "the general recommendation for actors in the areas investigated is not to postpone the needed investments and development for full UMTS service provisioning. Not only the telecommunications operators are at stake, but the value chain and partnering modes are richer and more vital than with the much narrower 2G approach."

Towards the end of the first decade of 2000, the business actors traditionally considered as equipment vendors, now widening their scope towards more end-to-end solution providers, have largely taken the initiative to boost the mobile ecosystem. Apple took the place of a forerunner in this technology disruption (for technology disruptions, see Adner 2002), where new application interfaces break into the mobile domain, and the synergies in Internet access through versatile equipment is eventually forming new ways to use services and thus creating new demand and requirements. The mobile device functionality has to be complemented with the full business architecture that combines all the roles and relationships in the new value networks of provisioning services like music, TV-programming, social networking, location based services, advertisements and e-commerce that may be composed of content, applications and charging from several providers. In the even more disruptive model by Google's Android operating system, the mobile device is not anymore a closed equipment to be used for purposes dictated by the operator or even device vendor, but is becoming a platform for applications from a wide variety of sources.

The problem has been for many operators that when they have tried to avoid the commodity “bit-pipe” provider role by keeping the control of the customers fully in their hands and, therefore, keeping the other actors out, or in too tight revenue pressure, have eventually run into the very danger they were afraid of. As the operators have driven themselves to competition with price and not innovation, the equipment manufacturers that have cultivated ecosystems for ever richer features and applications for advanced users, that have been also willing to pay for them, have got into a more innovative stance to invest in new services. In addition, Internet players with advertisement based revenue models have entered the scene of mobile services. The business system mobilisation is yet to soar and the system integrators may take a strong position in that ecosystem.

However, some operators were investing in the new service approach and offering even open access instead of “walled garden”. Hutchison 3G Austria reached the ARPU of 59.5 € for its 3G subscribers already in September 2004 (Alcatel 2005). In March 2007, 3 Group announced that through its strategy and activities in Australia, Austria, Denmark, Hong Kong, Ireland, Israel, Italy, UK and Sweden, its higher-value contract customers accounted for 45% of the total customers at the end of 2006. The average revenue per active user (ARPU) reached 45.63 € and the proportion of revenue derived from the higher margin “non-voice” services, which continued to grow in 2006, increased from 5% to 30% of the ARPU (3 Italia 2007). Both total ARPU and data service percentage coincide almost perfectly with our forecast for the year 2006 in

Figure 24.

The company predicted that it will be profitable before certain special items in the year 2006, but they have had to postpone that target since then (Business Mirror 2009). From 2006 on, the European incumbent operators have increased their provisioning effort of 3G service, accelerating the price competition. This has slowed the H3G Group’s subscriber and revenue growth and raised the marketing expenses further. After the recession from 2008 onward, the situation has turned to be even more challenging for profitability. Relating to both revenue and cost side, the H3G Group business case followed very much the patterns of Figure 25: “Economics of the Large country challenger UMTS business case” with yearly profitability break-even forecasted to take place after 2006.

Group 3 proved to be more of an exception in its approach, but this does not indicate that the presented modelling would have been wrong as such - this exception rather supports that it was a possible, even advisable approach and scenario to go for.

4.1.4.2 Estimation of required investments

After the downturn following soon after the UMTS auctions in 2000, there was a lot of dispute about the high costs of the UMTS networks, and that it is challenging for operators to recover from the unprecedented high costs of the UMTS licenses and rollout. Even the whole feasibility to build UMTS networks and, on the other hand, the mass provision of handsets was at stake in 2002, when the first results were published. Most European operators were hesitating and looking for short-term profits in the challenging economic situation. At the same time, many analytics suggested long delays in UMTS take-up. For instance, Forrester’s report ”3G’s Belated Break-Even” (Forrester 2002), suggested that only 10% of European mobile users will use UMTS in 2007, and that industry wide payback will be delayed until 2014. The first statement is low against the examination in the previous subsection, and was not encouraging for the actors to invest; the second statement being even more controversial, as the UMTS business has been quite profitable and the investments (including the license cost) are a minor part of the operators' costs, the bulk of them being in the operational expenditure side according to the costs studies presented.

Even as late as on July 30, 2006 the New York Times (O'Brien 2006) published an article stating: "European mobile phone companies spent $129 billion six years ago to buy licenses for "third-generation" networks that were supposed to give people the freedom to virtually live from their cellphones, reading e-mail, browsing the Internet, placing video calls, enjoying music and movies, buying products and services, making reservations, monitoring health - all from the beach, the bus, the dentist's waiting room, wherever they were." and "Over the long term, 3G runs the risk of becoming the Edsel of the mobile phone industry - an expensive, unwanted albatross rejected by consumers and bypassed by other, less costly technologies, some experts say."

The previous subsection dealt with the problems in 3G service diffusion. The accusation of UMTS being a too costly technology is, however, not justified according to the techno-economic modelling. The network build out costs for an incumbent operator were demonstrated to be reasonable and actually not so decisive for the business case as some other aspects. Only for the countries of small population but large area, like the Nordic countries, the rollout costs were critical if the strict regulatory requirements for coverage schedule and refusal of infrastructure sharing were stuck into.

The price levels of network equipment were actually eroding very fast due to the telecommunications downturn and fierce competition between the suppliers, and, on the other hand, the technology efficiency was developing faster than anticipated. The supposed competitive technologies like WLAN as handled in this study and mobile WiMAX in the next one, lost in the race against the widely deployed UTMS solution, including HSDPA already in 2006, and providing increasing economies of scale in the path towards LTE.

The modelling results demonstrated that the UMTS investments were reasonable and feasible to be started without delay in the dense areas, but needed to be checked for the right schedule for the sparsely populated area rollout. The investment challenge has not been in the UMTS as network technology, but in the more complicated application and service industry. As the operators did not charge strongly in this development, other business actors have, to a large extent, taken the initiative in the new innovations towards advanced mobile services and mobilisation of the all pervasive Internet.

4.1.4.3 Analysis of possible threats

The conclusions part of Publication 2 state, based on the techno-economic valuation of the business cases, the potential threats and related measures needed:

1) Service provisioning and take-up delay should be fought back as a potential eroding factor for the business case.
2) Prompt investments in UMTS are needed throughout the extended value chain
3) Authorities should not set requirements leading to uneconomic structures; models for infrastructure sharing and bandwidth sharing with MVNOs, for example, should be considered.
4) WLANs will have a minor direct impact on 3G businesses.

The assessment of the results afterwards shows that the stated suggestions were on the right track:

1) Delay in provisioning and thus service take-up took place to a certain extent.
2) After a couple of years waiting time the incumbents invested widely in the network infrastructure, but extensive investments to the services throughout the extended value chain did not happen; the mobile services usage and revenue started to become considerable only towards the end of the decade for most incumbent operators.
3) The requirements by the authorities relating to the license agreements did hinder the service provisioning somewhat in some sparsely populated areas in the beginning, but as the slowdown of the 3G development became clear, the restrictions concerning, for example, the infrastructure sharing were mostly relieved so that authorities are not to be accused for the delay in service deployment in Western Europe by suppressing the license owning incumbents' possibilities, but maybe rather for not supporting the other actors' like MVNOs's role in service provisioning.
4) WLAN and other technologies as UMTS competitors were among the main concerns at the time of the study, but the results suggested that 3G and public WLAN are rather complementary within a total mobile data services portfolio; this prognosis has hold also in the realised market development.

4.2 Technology competition in 3G and beyond service provisioning

[Publication 3: Harno, J. (2009a). Techno-Economic Analysis of Beyond 3G Mobile Technology Alternatives. *info, Emerald Group Publishing*, Volume 11, Issue 3, pp. 45-63.

Publication 4: Harno, J., Katsianis, D., Smura, T., Eskedal, T., Venturin, R., Pohjola, O-P., Kumar, K. R. R., Varoutas, D. (2009a). Alternatives for mobile operators in the competitive 3G and beyond business. *Telecommunication Systems*, Volume 41, Issue2, pp. 77-95.]

4.2.1 Background

These studies are based on the modelling results from the year 2006 and focus on business cases of an incumbent mobile communications actor, i.e. one who has an existing 2G network with a large customer base and wants to deploy its own 3G network to survive in the new 3G and beyond service competition.

The scope here is the typified “Large” Western European country with a population of 65 million, as defined in Chapter 3. This study setting includes, and compares, two alternatives: a UMTS deployment, and a mobile WiMAX (as a new competing 3G technology deployment) in the supply of the new broadband mobile services.

As we want to compare the business prospects between different mobile technology paths, the whole business of the mobile operator will be modelled, including the older generation technology it starts with. The technologies may complement each other in provisioning the full set of services to customers in different segments. Many services can be provided through more or less advanced technology, but in our modelling we introduce different demand, depending on the user experience supported by the technology.

Since an incumbent actor is modelled in the base case, it is assumed to have the 2G technology already in place and some enhanced data capacity (EDGE) possible to be rolled out easily as an upgrade to the 2G network. Deviating from the modelling in the previous studies (Section 4.1.) the revenues and costs of the operation of the older generation technology are included in the business case. This is essential for true comparison in this study, because the WiMAX technology is spreading out later than the UMTS, so that the WiMAX business case relies more on the 2G technology and EDGE than the one with the UMTS path. Different technologies may also lead to different optimal rollout strategies relating to dense and sparsely populated areas.

In this study setting, the license cost are not modelled, as it is considered a sunk cost for those who already paid for their licenses, but those actors that have not got a license have to compete from that starting point. This study is to compare their prospects.

The analysis method in the study is developed to model separately the Service operator and the Network operator sides of the business. However, as investigating incumbent actors, there is usually a clear connection between them. So in this scenario only one Service operator and one Network operator are linked together. Even as such, this separation gives interesting insight into the economic dynamics in and between these entities.

The licensed UMTS operator builds on UMTS plus HSPA, continuing to 3GPP LTE in the longer run. The LTE, however, is not modelled in this study, due to the time frame, which does not allow for the full revenue potential related to the investments. The competing 3G technology, was first defined loosely as “OFDM technology”, but was later, as the technology development was defining, selected to be mobile WiMAX (IEEE 802.16e) deployed in the licensed 3.5 GHz spectrum. The width of the used frequency band is supposed to be 10 MHz. The characteristics of WiMAX include full IP compatibility throughout the network, and an effective OFDM radio frequency utilisation. Within both basic alternatives full GPRS coverage is already built, and EDGE technology is possible to be utilised for a fast initial upgrade for new services. It will be seen that in the WiMAX case the EDGE technology is especially crucial as the WiMAX technology is available later than UMTS, and due to the shorter range of the cells, it is not feasible to cover the suburban and rural areas with mobile WiMAX. This is much due to the relatively high 3.5 GHz frequency band utilised.

As all the investigated technologies from GSM to UMTS or WiMAX differ in parameters that affect the user experience and thus the service take-up and usage, the modelling of these characteristics is of crucial importance. To analyse this effect, a separate End-user model has been utilised.

This study aims to find answers to the following types of questions: Is it possible, in the Western European context, to utilise alternative technologies to compete with UMTS, in the case that no license for UMTS frequencies is possessed? Is an intermediate EDGE deployment feasible or necessary? Does the HSDPA upgrade increase the UMTS profitability or not? How will the business situation differ for the Service operator compared to the Network operator? What are the differences, in respect to new services and their revenue potential, between the available radio technologies? What impact on economic end results would the differing cost structures of the studied approaches generate? What are the economic opportunities, potential risks and vulnerabilities in each case?

In this study, three technology cases are compared: “UMTS with HSPA”, “UMTS without HSPA”, and “WiMAX deployment”. The latter two cases are further divided into cases with or without EDGE deployment, as a complementing technology.

As indicated in relation to the fists business scenario of UMTS/WLAN (Chapter 4.1) there was a lacuna in the available research providing quantitative 3G and beyond business case modelling with detailed technology and business related parameters. Concerning the WiMAX business cases, some techno-economic studies were published (e.g. Smura, 2005), but they were concentrating on fixed wireless WiMAX, as the parameters and schedule for mobile WiMAX were largely unknown. A recent study (Runarsdottir, 2008), however, includes a narrow scope techno-economic comparison of mobile WiMAX and HSDPA deployments in Reykjavik, Iceland, the revenue side analysis consisting though only of three alternative access packages of different data rates. This study, in accordance to the thesis results, considers the HSDPA solution economically more viable.

Combining the technology insight with business aspects was required to support justified technology strategies in the obscure technology evolution situation, as this evolution and its schedule is dependent on the business actors that bring out the products, and the services based on the them, within the value network (or ecosystem). As mentioned previously, groundbreaking research in the telecommunications techno-economics was performed in a series of EU and then EUREKA funded projects, the last one being the ECOSYS project. The consortium approach provided good basis for this kind of undertaking that requires theoretical knowledge and practical data from several business and technology development actors and research institutions, being unique in its scope as a public research project. The author of the thesis was strongly involved in this work, leading the ECOSYS Work Package for mobile business cases. Based on that work he has authored and co-authored several journal and conference articles about the techno-economic comparison of 3G technology alternatives, two of which are included in the thesis (Harno 2009a; Harno et al. 2009; Stordahl et al. 2004; Katsianis et al. 2007; Harno 2005b; Harno, 2005c; Harno et al. 2005a; Harno et al. 2006a; Harno et al. 2006b; Harno et al. 2006c; Harno 2006a; Harno 2006b; Harno 2007a; Harno et al. 2007; Harno 2010). In some of the articles, also newcomer 3G operator, MVNO and CDMA450 business cases are investigated.

4.2.2 UMTS versus Mobile WiMAX in 3G service provisioning

A study period of eight years and a discount factor of 15% are used in these analyses. The defined values of the parameters are based on the standardisation and in-house data provided by the study partners from their field data, forecasts, tests and simulations. The basic assumptions, modelling principles and parameterisation of the business cases were described thoroughly in the method chapter (Chapter 3).

An incumbent actor will be concentrated here, i.e. one who has an existing 2G network, and wants to deploy its own 3G network to survive in the new 3G and beyond service competition. This study setting includes, and compares, two alternatives: UMTS deployment (with license), and a new competing 3G technology deployment. In both cases, an initial EDGE deployment is considered. For the UMTS case, also the potential savings through inclusion of HSDPA upgrade have been studied. For this scenario, only the “Large” country type has been analysed (for country types see Chapter 3).

This analysis approach is unique in published literature as linking three models dynamically together; namely the Network operator cost modelling, the Service operator service provisioning, revenue and operational expenditure modelling, and the end-user benefit and behavior modeling, all relating to the emerging advanced mobile communication business and technologies.

As an evolution path for GSM and GPRS technologies, EDGE, UMTS and HSDPA technologies are modelled. Mobile WiMAX technology has been modelled as representing an alternative technology approach for an operator without a UMTS license. The technical and cost parameters of each technology have been presented in Chapter 3. Worse availability and choice of the mobile WiMAX handsets is seen in the lower service take-up figures in the beginning. As the mobile WiMAX technology has been deployed in the higher bands, it has a smaller site coverage area than UMTS. This has cost effects especially in the rural areas, where the capacity need per surface area is low. For these reasons, mobile WiMAX has been deployed only in the urban areas.

Although there are already several business case analyses for the fixed WiMAX, no comprehensive quantitative analyses, except some commercial analyst reports, are available on mobile WiMAX. An extensive list of references on WiMAX technology is available in the WiMAX Forum Internet pages (WiMAX Forum 2009), and on UMTS and HSDPA in the Global mobile Suppliers Association Internet pages (GSA 2009).

The WiMAX, UMTS and HSDPA parameters presented in Chapter 3 are based on simulation results for real environment and normal usage conditions. Many earlier studies are based on theoretical pre-implementation parameters.

4.2.2.1 Rollout schemes and related investments

The study period starts from the year 2006 (first calculated investments) continuing until the year 2013. In the beginning, the Network operator has the GSM capacity built up to support the traffic level at the year 2006. Also the initial quite low data traffic is supported by the existing GPRS capability. After that point, the needed extra GSM/GPRS capacity is rolled out and calculated in the model. If the EDGE capability update is decided to be rolled out, it takes place in the year 2006.

For the UMTS there are regulatory rollout requirements, which differ from country to country, but generic schedules are used here. UMTS rollout starts in the year 2006, and the service is provided from the beginning of the year 2007. The deployment starts at the same time in all area types, but takes one year to cover the Dense area, two years for the Urban, three years for the Suburban, and 7 years to cover the whole rural area.

The rollout of the base stations (BS) is based on three pentagon cells (sectors) for each BS. Other equipment is counted accordingly, either based on BS amount, or the required capacity, as described in Chapter 3. After the BS coverage has been built up, the needed additional BS/TRX capacity is rolled out in the previous calendar year of the foreseen traffic amount according to the capacities (throughputs) of the particular radio technology.

The mobile WiMAX rollout is considered later than in the UMTS case, starting in the year 2007, so that the service provisioning can start in the beginning of the year 2008. The rollout schedule has the same pace as with UMTS, but without the suburban and rural rollout. The development of population coverage for different technologies is presented in Figure 28. In addition, the potential traffic from the devices using the most advanced technologies has been presented.

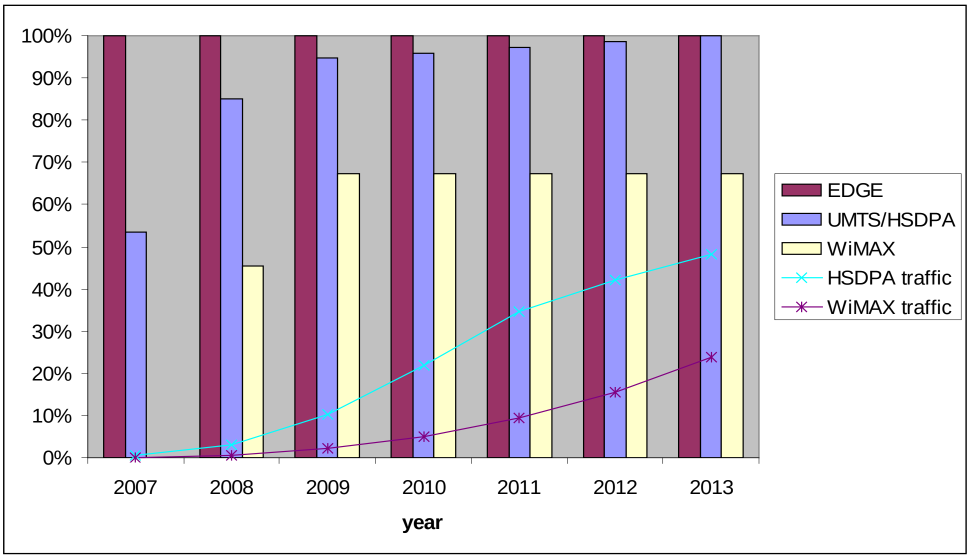


Figure 28: Technology rollout schedules (population coverage) (Publication 3)

4.2.2.2 Services and revenues

Demand modelling is based on penetration estimates for different technology subscribers in selected segments and their forecasted usage patterns. End-user modelling gives the usage amounts for active users of each service, per each segment and each technology, as described in Chapter 3 introducing the utilised methods.

The parameters relating to the user experience differ by technology and user segment. The most important differences between technologies are: Network blocking/unavailability, Technical trouble or delay, Practical upstream bit rate, Practical downstream bit rate and Perceived quality of the service channel (differs especially for high capacity requiring services, like video call or streaming). All the above parameters are clearly better for the advanced technologies UMTS and WiMAX compared to the lower level technologies EDGE and especially GPRS. The differences between user segments include their valuation between time and money and their capabilities to use the services. The applied tariffs and tariff erosion are the same for all technologies.

The role of the End-user model is to create a link between service usage and user experiences with different technologies, user segments, and services. The reference parameter values used to calibrate the initial usage amounts with the set tariff levels are chosen between the advanced technology values and EDGE parameter values. Based on the parameters, the End-user model calculates the benefit, cost, and success figures for each technology, service, and user segment, and for the reference. The actual paid tariff is part of the costs, which include also the so-called opportunity cost due to loss of available alternative benefits. Valuation of opportunity cost takes into account also the value of time, which differs between the four segments used in the modelling.

The service usage for technologies, user segments, and services are calculated using the End-user model by comparing the benefit, cost, and success figures with the reference values. As the parameter values get better along with the advanced technologies the usage grows from the reference values, and respectively in the case of lower level technologies the usage diminishes as the user expectations are not met. For more about the utilised End-user model, please refer to the sub section “End-user modelling method” in Chapter 3.

Upon the usage figures we have applied the market size and market share of the operator, technology penetrations, and rollout schedules, to get the user amounts. As the End-user model gives the usage volumes for active users of each service in each segment and technology, we have in addition estimated the penetrations of active users of each service type in each segment and technology.

Estimated percentages of different technology subscribers are based on device/handset penetrations. When the population coverage is incomplete, the potential usage and traffic amounts are only partially realised according to the available coverage. The figures are dependent on the particular Network operator and Service operator provisioning. The population coverage development by the Network operator was presented in Figure 28. It should be noted that, for example, EDGE penetration is tracked here as for an operator who provides EDGE network, not as general EDGE penetration.

It is estimated that if the operator goes for UMTS, its data subscriber base is migrated quite quicly from EDGE to UMTS, boosted by subscription packages including devices and related device subsidies. WiMAX is in a weaker position to reach mass penetration in the Western-European mobile market due to the path dependency of the dominant actors and the benefit of scale in handsets, but has its possibility in the more niche market of the special IP centric approach. The penetrations for users of different technologies are presented in Figure 29. Those data users not having any of the presented technologies are presumed to be using GPRS.

Subscribers utilising more advanced technologies are supposed to have also the less advanced technologies in use. WiMAX penetration is estimated to be clearly lower than UMTS, due to the device availability, form and price factors. Potential laptop users, for example, are considered to be much lower in number than pocket size handset users.

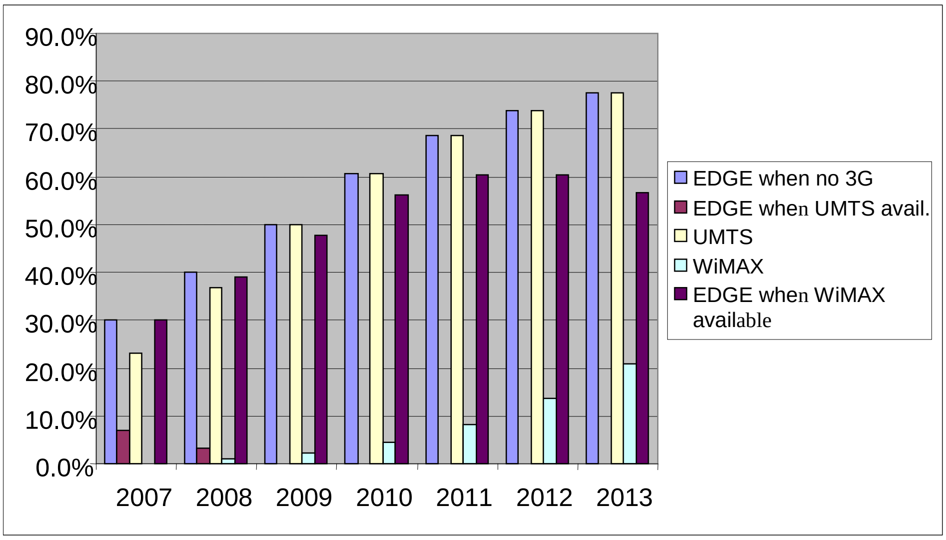


Figure 29: Potential users of different technologies (Publication 4)

The customer base is assumed to be 16.5 million in the year 2007, comprising a 30% market share of mobile users from the total population of 65 million. The penetrations of active users are out of this user base. Voice and SMS services are supposed to have 100% penetrations in all segments. Each technology induces slightly different penetrations for data services, so that higher capacity technology imposes more users, but this increase is not as significant as the usage amount difference calculated in the End-user model.

The Service operator’s revenues are calculated by combining the technology related user behavior from the End-user model (usage amounts for the selected price level), with segment sizes and related actual active service users. The earlier the enhanced technology is deployed, the more traffic is generated, but only in the limits of general demand development and device availability. The generated average revenue per user (ARPU) is clearly higher for the more advanced technologies. On the other hand, also the costs are higher for early capacity deployment.

Figure 30 and Figure 31 present the voice and data Average Revenue Per User (ARPU) developments depending on the technology (Harno et al. 2007); in the first figure, when plain GPRS is provided, and in the second figure for those users who have the UMTS service. It should be noted that as in the beginning few subscribers have the UMTS service, this ARPU is much above the average ARPU of the operator. Without UMTS, the ARPU of the operator is estimated to erode substantially throughout the study period.

There are no major differences in voice traffic amounts, as only a slight quality of service (QoS) benefit is assumed for UMTS users. Regarding the data traffic, the difference between UMTS and WiMAX is mainly due to better coverage of the UMTS network, but QoS is estimated to create a clear difference for the advantage of the higher bit rate and lower latency technologies, as seen in the graphs. This indicates that high bit rate technologies are essential in the medium and long term competition, if the ARPU is to be sustained. As UMTS/HSDPA seems to guarantee higher wideband/broadband data user penetration, it is in a stronger position than WIMAX.

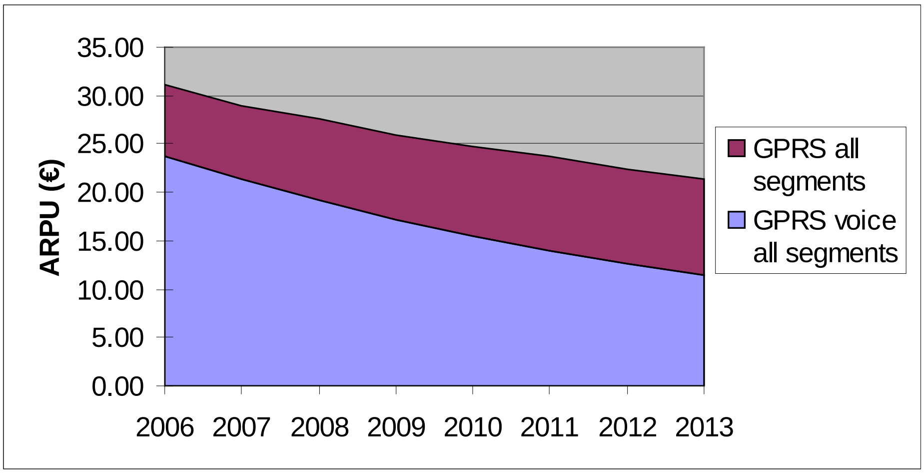


Figure 30: GPRS subscriber ARPU development

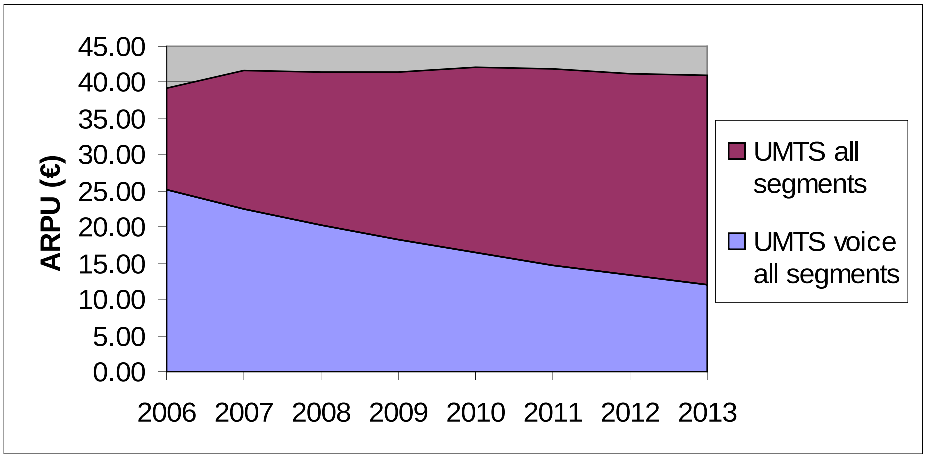


Figure 31: UMTS subscriber ARPU development

The Network operator's revenues are based on the traffic amounts calculated in the Service operator model. The wholesale tariff levels are defined so that the operating profits of the Service operator and Network operator are at the same level in the UMTS case. The same wholesale tariffs are applied for all cases. Wholesale prices that the Service operator pays to the Network operator in the year 2006 are as follows, with 15% yearly price reduction applied thereafter:

- Narrowband conversational (voice): 0.011 € / min (inbound and outbound)
- Wideband conversational (video telephony): 0.043 € / min (inbound and outbound)
- Data: 0.15 € / MB (both directions)

The annual price reduction is quite substantial compared to the average tariff erosion in the recent years, but is in accordance with the high increase of traffic foreseen. Nevertheless, it causes the Network operator revenues to grow. At this phase, the wholesale data traffic pricing is not differentiated between, for instance, streaming, interactive, and background traffic classes.

4.2.2.3 Required investments and operating costs

The required investments and operating costs are calculated according to the modelling and technology specific data as presented in Chapter 3.

4.2.3 Modelling results

Five sub-scenario results will be presented based on Publication 3, and the respective risk and sensitivity analyses according to Publication 4: “UMTS with HSDPA plus EDGE deployment” “UMTS plus EDGE deployment”, “UMTS without EDGE deployment”, “WiMAX plus EDGE deployment”, and “WiMAX without EDGE deployment”. For the NPV (net present value) calculations, the discounts rate is 15%, due to the fact that in the turbulent markets and heavy technology competition the future profits from the investments are somewhat unsure. With a reasonably high discounts rate, the possibly positive results are more reliable. The presented NPV does not include investments made before 2006 and potential positive cash flows after 2013, so it should be interpreted more like discounted cash balance over the years 2006 – 2013, but a slight rest value of the equipment is included.

4.2.3.1 Cash flows and resulted NPVs

In the UMTS cases, the Service operator’s net cash flow increases towards the end of the study period. For the mobile WiMAX cases, such growth is not seen, and the end results are more modest, although the cash flow clearly remains positive. This is mainly due to UMTS being more mature technology (handsets and network) in the beginning, being able to serve all types of services. From the cash flow results of the model, it can be seen that the revenues from the advanced services grow steadily in the UMTS case, as the demand and usage increase faster than the tariffs are falling, especially in the middle period. The results are improving also because the costs are levelling off towards the end of the study period. For the WiMAX case, the revenues do not grow to such a level, because of the lower amount of acquired high capacity users. See Figure 32 and Figure 33 below.

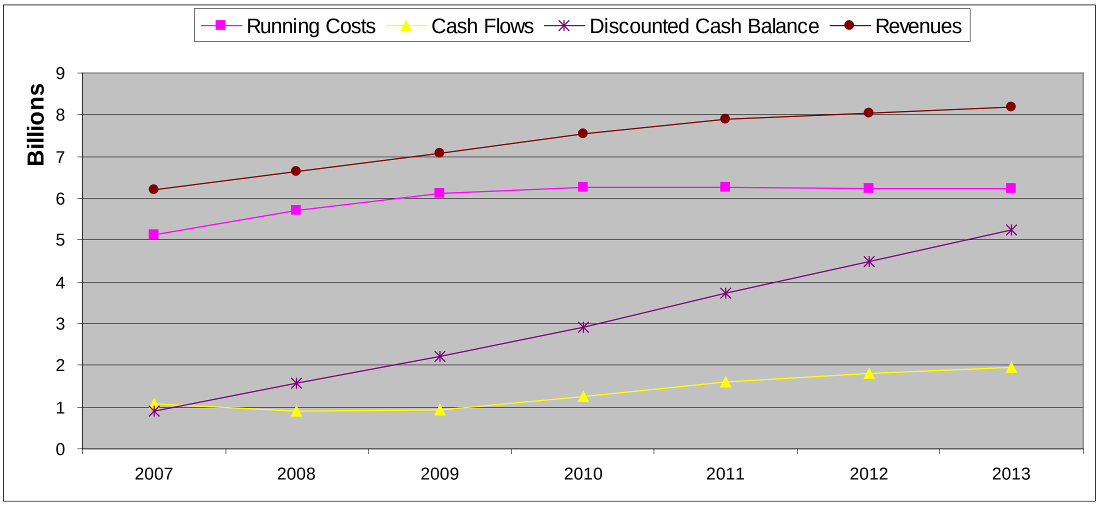


Figure 32: Cash flows of the Service operator (UMTS+HSPA) (Publication 4)

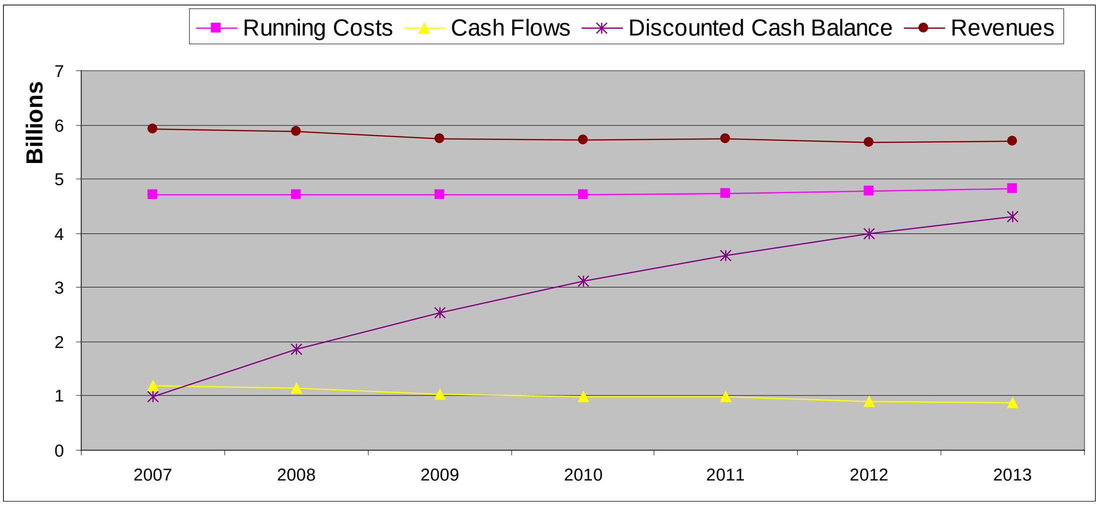


Figure 33: Cash flows of the Service operator (WiMAX) (Publication 4)

The Network operator, on the other hand, has a negative cash balance for all cases in the beginning, but then in two years the discounted cash balance turns to steady growth. Due to the negative cash balance in the beginning the Network operator's technology risk is higher compared to the Service operator, who does not have to make such large vestments. In the UMTS case, the Service operator partner can catch more advanced data users, so that the traffic, and thus revenues, are estimated to grow higher also for the Network operator providing UMTS. The investments or operational costs do not show crucial differences between the technologies. However, because of less traffic (and thus revenues) the payback for the WiMAX investment is not so strong in this kind of operator case. Cash flows of UMTS and WiMAX cases are presented below in Figure 34 and Figure 35.

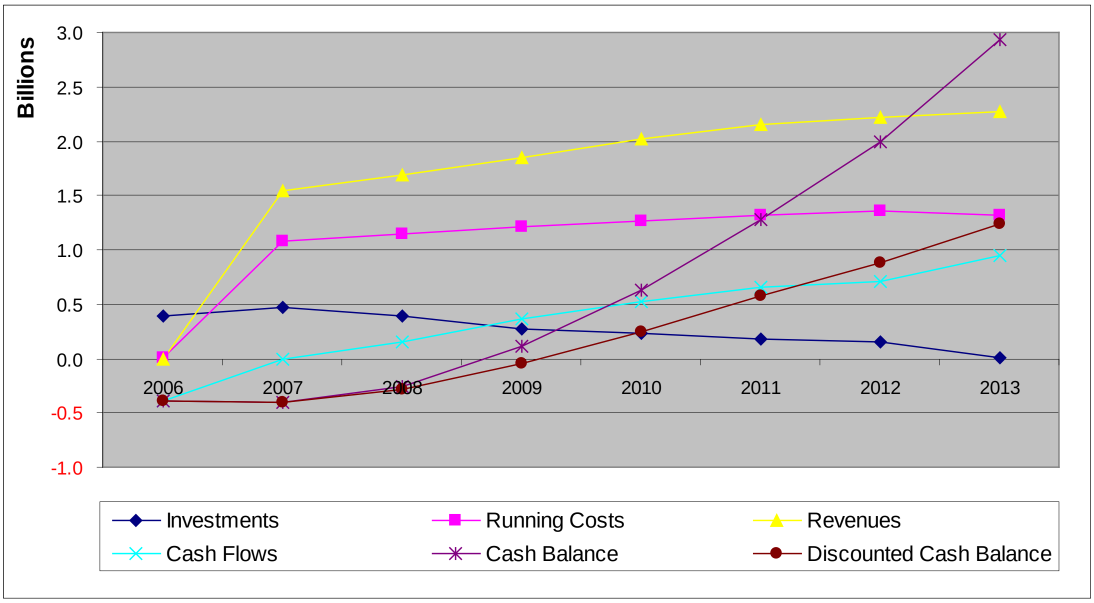


Figure 34: Cash flows of the Network operator (UMTS+HSPA) (Publication 4)

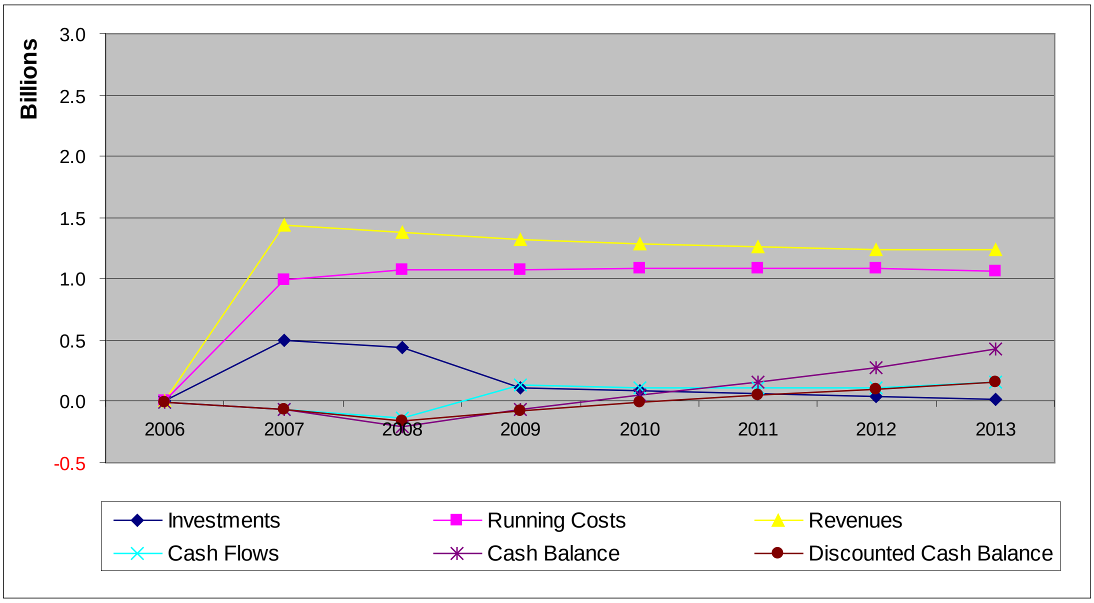


Figure 35: Cash flows of the Network operator (WiMAX) (Publication 4)

According to the results shown in Table 15 below, it seems that successful competition is possible also by utilising another 3G technology, when the UMTS license is not available. The results for mobile WiMAX are somewhat lower than for UMTS, but the license costs (which are not included here), might be lower for the other technology. However, there are still uncertainties relating to the dissemination of technologies, which are not yet in the mature mass production phase – either for the network part, or especially for the device/handset part.

This increases the risks for mobile WiMAX cases related to the potential delay in market maturity. For the HSDPA, the future concerning the device and network technology availability and maturity is already more assured.

Table 15: Network operator and Service operator investments and NPV summary

TECHNOLOGY DEPLOYMENT	UNIT	NTWOPER. CAPEX*	NTWOPER. OPEX*	NTWOPER. NPV	SERVOPER. CAPEX*	SERVOPER. OPEX*	SERVOPER. NPV
UMTS/HSDPA with EDGE	B€	1.57	5.08	1.47	0.140	24.5	5.24
UMTS with EDGE	B€	1.75	5.24	1.23	0.140	24.5	5.24
UMTS without EDGE	B€	2.46	5.48	0.310	0.140	24.5	5.10
WiMAX with EDGE	B€	0.919	4.40	0.330	0.103	19.7	4.32
WiMAX without EDGE	B€	1.88	5.40	-1.88	0.103	19.2	3.02

* **discounted** values, from year 2006 to 2013

Plain EDGE deployment does not give optimal results due to lack of appeal to growing number of heavy data users, but is best as an auxiliary solution together with UMTS or WiMAX. The auxiliary EDGE deployment has clearly a higher effect on the Network operator business than on the Service operator. This reflects that the investment savings are considerable. For the 2G business actor going for mobile WiMAX as 3G technology, the intermediate EDGE deployment is crucial, so that without it the NO WiMAX case becomes heavily negative. These findings relate to the fact that EDGE is deployed in the beginning of the study period, and if the EDGE is not deployed, more low capacity GPRS base stations have to be rolled out, raising the costs dramatically in the WiMAX case. As the UMTS rollout is one year earlier, the effect is not so strong.

The revenue potential from UMTS and mobile WiMAX relate to the End-user modelling results indicating that the growing revenues of especially the business segment can only be captured with the higher-level technologies. HSDPA has been modelled here only as a cost saving factor, as the data capacity per base station is increased, but it will probably also have some impact to increase spending.

4.2.3.2 Risk and sensitivity analysis

The most important parameters and modelling aspects, as well as the risk and sensitivity analysis principles were presented in the methods chapter (Chapter 3). Here the model outcomes with the base case assumptions are presented together with the risk and sensitivity analyses that take into account the uncertainties within the assumptions. Statistical simulations illuminate the risks involved in the business cases. Further on the conclusions that can be drawn from the modelling supplemented with the risk and sensitivity analyses are presented.

The parameter values, relating to new service take-up, service usage, data traffic volumes, tariff levels, revenues (ARPU), market shares and technical radio network parameters are only estimates, the best available expert guesses, and the impact of deviation related to each factor should be considered. Because of the long time horizon, the new technologies and especially the services of which there is no experience yet, it is not possible to achieve exact economic figures for specific business cases. To serve the strategic decision making, it is seen to be more important to have some means to compare the alternative scenarios by estimating the opportunity and risk profiles of these alternatives, than just provide one set of key figures.

In the sensitivity analysis, the selected parameter set has been varied using normal distribution. The model results are then run with parameter values drawn randomly from these distributions (Monte

Carlo simulation). As a result, the parameters are listed in the order of significance, according to their impact on the results.

In the risk analysis the result distributions are presented, supplemented with Value at Risk (VaR) measurements, commonly used for financial portfolios (ECOSYS Deliverable 11 2005). Instead of NPV figures, Discounted Cash Balance is used, as the rest value that is included in the NPV is an unsure value, although it was assumed to be small. VaR reflects here the riskiness of the business case, and presents the upper limit for the lowest 5% of the stochastically calculated possible results. Hence, it represents the minimum result that can be reached with high (95%) certainty. The total variance, as the sum effect of all parameter variations together, is presented too, reflecting in a way the "volatility" of the particular business case.

For the sensitivity and risk analyses, Monte Carlo simulations were run using the Crystal Ball™ software. Parameters were varied stochastically by using a multiplier varying according to Normal distribution with the following settings: Mean=1.00, Std. Dev.= 0.10, Trials=1000. In addition, as the mobile WiMAX launch schedule is not yet secured, a delay parameter is used and an assumption that the WiMAX penetration delay follows the exponential distribution is made. The WiMAX penetration delay varies from 0 to 1 year. The Rate parameter used in the exponential distribution is 3.00. The factors varied for the cases are:

- Penetration of 3G services (relates to penetrations of the individual services, i.e. percentage of the active users).
- Data service traffic (relates to usage amounts of the data services by the active users, but the revenue is kept constant; data service revenue, contrary to voice service, is not tightly connected to the traffic volume).
- Data service ARPU.
- Voice ARPU.
- Start market share.
- End market share.
- Wholesale tariff per minute.
- Wholesale tariff per MB.
- UMTS/WiMAX cell radius (affecting only Network operator case).
- Equipment investments (significant only in Network operator case).
- WiMAX penetration delay.

Results of the risk and sensitivity analyses for the different operator cases are presented below:

1) Service operator with UMTS + HSPA

Discounted Cash Balance in base case	5.16 B€
Mean/Median Discounted Cash Balance	5.13 B€ / 5.05 B€
St. Deviation of Discounted Cash Balance	1.30 B€ / 25%
Value at Risk, VaR (q=95%)	3.06 B€

For the figures of Discounted Cash Balance distribution with the Mean and Value at Risk points, please refer to the enclosed article "Techno-economic analysis of beyond 3G mobile technology alternatives" (INFO Journal). The sensitivities against the most important parameters are presented in Figure 36.

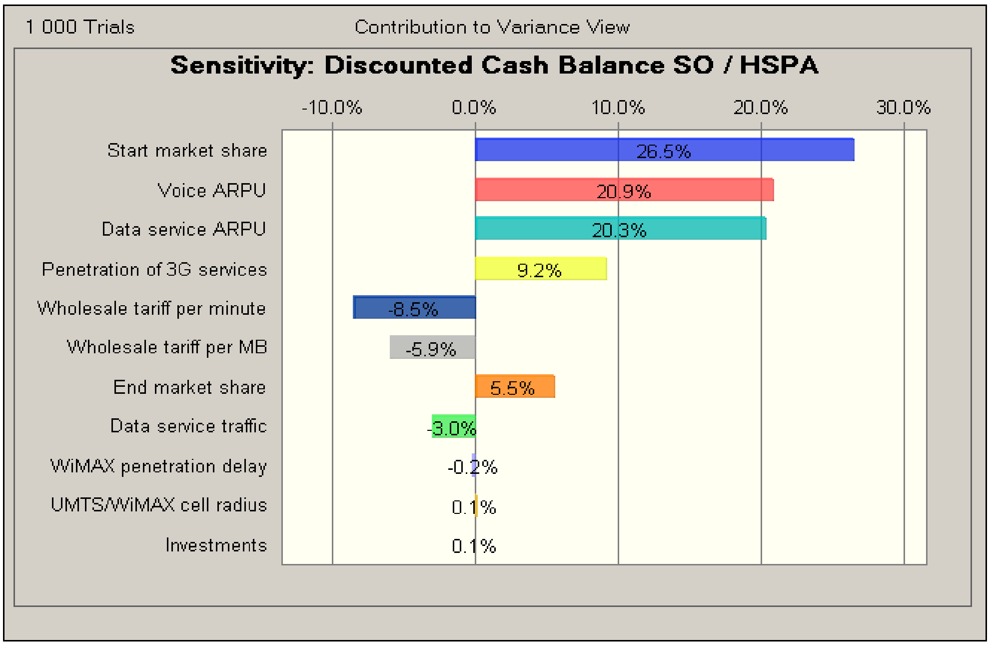


Figure 36: Sensitivity analysis: Service operator with UMTS + HSPA (Publication 3, from Crystal Ball™)

From these results it can be seen that the UMTS/HSPA Service operator case is quite robust, not a great variance and clearly a positive value at risk. The Start market share is the most important single parameter in this case reflecting the good profitability of the voice service still in the beginning of the study period. Also the discounting that relates to the uncertainty of the future revenues reduce the impact of the End market share, for example.

The ARPU levels of both voice and data services are very important for the Service operator results in the UMTS/HSPA case; more important than the penetration development of the services, as some of the services will reach the ceiling of 100% penetration during the study period with no room for growth, and, on the other hand, the usage also increases the traffic and thus costs for the Service operator.

The cost side, meaning Wholesale tariffs and data volumes are not as important for the Service operator, and as data services (measured in MB) dominate only in the later period their impact is lower than the voice services (minutes).

2) Network operator with UMTS + HSPA

Discounted Cash Balance in base case	1.23 B€
Mean/Median Discounted Cash Balance	1.21 B€ / 1.19 B€
St. Deviation of Discounted Cash Balance	0.86 B€ / 71%
Value at Risk, VaR (q=95%)	- 0.15 B€

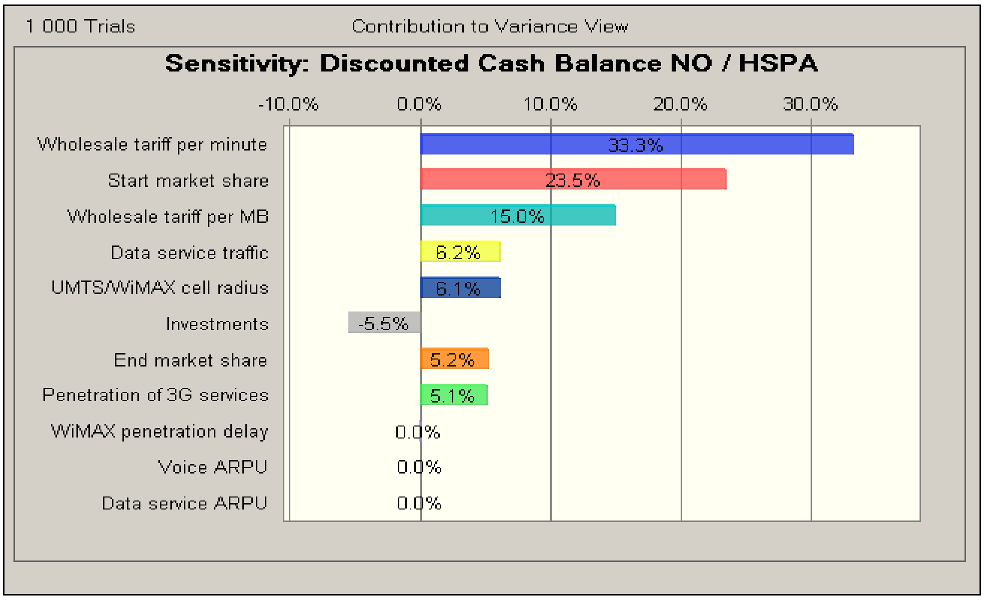


Figure 37: Sensitivity analysis: Network operator with UMTS + HSPA (Publication 3)

From these results it can be seen that the UMTS/HSPA Network operator case is not as robust as the Service operator case, but has a substantially higher variance (volatility) against the input parameters. The value at risk is slightly negative compared to the mean result. The income side of the Network operator, especially the Wholesale tariff of the voice minutes, is clearly the most important factor for this case. The data tariff is less important, but its impact is increasing towards the end of the study period. The Start market share of the Service operator counterpart is also highly important.
The next five factors are quite near each other in impact. For the Network operator, it is better the more data intensive the services are for generating more wholesale revenue. The cost related technology parameters, Cell range and Investment price level, have reasonable significance. Cell radius is slightly more significant, as most of the investments go to the radio network, and cell radius increases the radio network costs more than linearly.

End market share impact shows up as being rather modest over the study range analysed, as also investments are reduced with lower market share, but surely it has an essential effect on the position after the study period.

3) Service operator with WiMAX

Discounted Cash Balance in base case	4.39 B€
Mean/Median Discounted Cash Balance	4.48 B€ / 4.42 B€
St. Deviation of Discounted Cash Balance	1.09 B€ / 24%
Value at Risk, VaR (q=95%)	2.37 B€

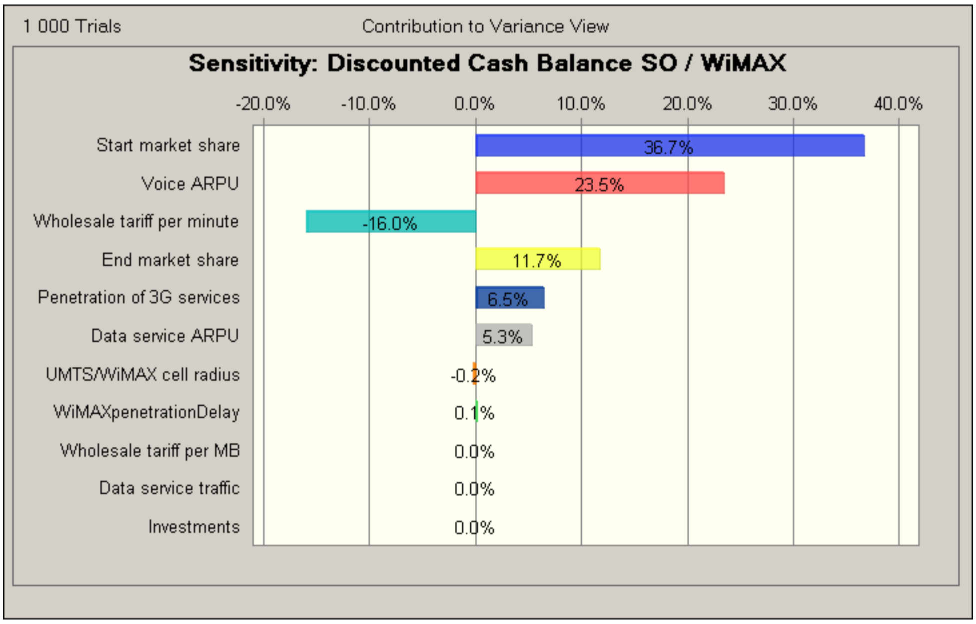


Figure 38: Sensitivity analysis: Service operator with WiMAX (Publication 3)

Again for the Service operator, as in the HSPA case, the case is quite robust, reasonable variance (volatility) and clearly a positive value at risk. The Start market share is again the most important single parameter reflecting especially the good profitability of the voice service still in the beginning. Voice ARPU is very important for the WiMAX Service operator results, but the data service ARPU not so much - due to the limited data user penetration in this case.

For the same reason the significance of the Wholesale tariff per MB is low compared to other parameters. End market share has higher relative importance for the WiMAX Service operator than for the UMTS/HSDPA operator, higher than the Penetration of the 3G services or Data service ARPU.

WiMAX penetration delay has minor significance, because its penetration is anyhow assumed to grow only towards the end of the study period; in the early days the EDGE technology compensates well the lack of WiMAX provisioning.

4) Network operator with WiMAX

Discounted Cash Balance in base case	0.20 B€
Mean/Median Discounted Cash Balance	0.12 B€ / 0.13 B€
St. Deviation of Discounted Cash Balance	0.67 B€ / 580 %
Value at Risk, VaR (q=95%)	- 1.04 B€

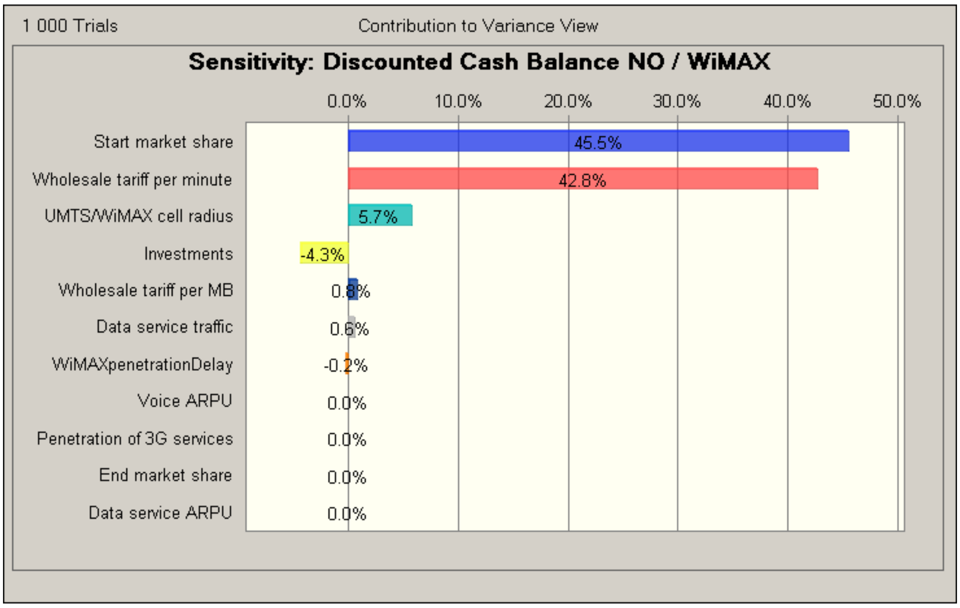


Figure 39: Sensitivity analysis: Network operator with WiMAX (Publication 3)

The WiMAX Network operator case is clearly unstable having a very high variance (volatility). The value at risk is deeply negative in comparison to the low mean result. For the WiMAX Network operator case the Start market share and Wholesale tariff per minute (voice) are dominating vitally. This reflects the situation where the operator is very much relying on the strong position of the mobile voice in the beginning. As seen from the sensitivity graph, the technical parameters are important, but not comparable to the first two.

End market share is significant in the HSPA cases and WiMAX Service operator case, as it relates to the revenues and profits in the later period. However, in the WiMAX Network operator case the increased traffic and revenue is almost totally undone by the needed auxiliary investments. The WiMAX penetration delay again has a minor significance also for the Network operator.
With the assumed penetration of WiMAX among its customer base the WiMAX Service or Network operator cannot make the 3G data services a very significant part of its business.

A different kind of business case, however, would give a different view on WiMAX based service: for example, a start-up business building a new customer base relying in all provided services on WiMAX devices and network. It might be geographically or service-wise focused on some customer groups.

From the risk analyses it can be concluded, in the first place, that the Service operator cases are more robust than the Network operator business cases. The mobile WiMAX Network operator case is particularly vulnerable, as being not very strongly positive in the first place, and having a very high volatility, leading to a clearly negative Value at Risk (VaR). Both NO cases have high volatility (standard deviation) in the results compared to the Service operator cases. This is at least partly because of their investments compared to revenue are clearly higher than in the Service operator cases; this increases the possibility of higher losses and thus the level of risk.

To improve the analysis especially of the Network operator cases, the Real Options method could be applied. As including the possibility to introduce flexibility in investment decisions, it would potentially increase the accuracy of the modelling, in allowing deferring or completely abandoning investments in case of low demand. This would decrease the losses in the down side of the potential outcomes, thus possibly increasing the Value at Risk.

4.2.3.3 Interpretation of results

This business case modelling studied a European operator with a high market share, continuing into 3G services from the basis of GSM, GPRS and EDGE. The UMTS path is seen to lead to first HSDPA, then to full HSPA, and eventually possibly to the 3GPP LTE type of radio network. However, due to the study time frame (2006-2013), the full LTE technology introduction has not been included in this study. It is demonstrated that the mobile WiMAX is needed to be complemented first with the EDGE (or other 2.5G) technology, but the high data traffic users are later served with WiMAX radio in addition to GSM/EDGE.

The presented results illustrate the value potential of the beyond 3G operator cases with different technology paths. When interpreting the results, attention should be paid to the presented parameters that restrict the applicability to certain types of operator cases. Moreover, it should not be looked to only plain NPV to rank the cases, but to look at the sensitivity relating to different parameters and the volatilities in the results. Analysing the Network operator part and Service operator part separately gives more informative results than doing the analysis as a combined case, even though both business roles may be part of a single operator business.

The results of the modelling indicate that both the UMTS path and the approach to build on mobile WiMAX technology can provide for profitable business within the selected framework. However, in the large mobile operator framework, the UMTS path is indicated to be more profitable, leading to a more secure position in the end of the study period, and to be more robust as analysed against the identified uncertainties.

Especially the WiMAX Network operator business case proves to be risky, but if combined with WiMAX Service operator business case, the total case gives good results and has also a positive Value at Risk (VaR) indicator. Although in the UMTS/HSPA case the operational profit rate is near the same level for both Service operator and Network operator, the risk analysis results suggest that the Network operator should be given a greater part of the revenues, which indicates that the wholesale price level should be higher. The higher share of irreversible investments should be compensated for by higher expected returns.

When looking beyond the year 2013, high-speed IP data traffic will continue to grow in importance. Thus introduction of high capacity technology through the UMTS path or WiMAX will be essential in the competition. In the Western European context, this study suggests that the UMTS/HSPA approach would give the most lucrative path for the high market share incumbent operator, due to the potential for high adoption of new services that are provided cost effectively for the high-speed data users during the studied time period.

In the main scenario a high market share has been assumed as for an incumbent actor. For a new entrant to the Western European market without a 2G network the situation is more challenging, as can be seen from the two other scenarios presented in the enclosed Publication 4. It would be possible to act as an MVNO in the 2G market, and build only the 3G IP overlay with mobile WiMAX. In this case too, the challenge is to get a large enough customer base to compete with UMTS operators – as the economies of scale work for the UMTS actors' benefit in the established Western European market. As the challenge is more on the network provider side, one possibility for the WiMAX Network operator could try to find several MVNOs to sell their IP based services (including VoIP) operating on the deployed WiMAX network.

4.2.4 Assessment of the technology competition studies

The main outcome from the study was that the UMTS technology path clearly had a stronger economic position. This was emphasised for the case of the Network operator, as the combination of network and device availability reduces the traffic and thus revenue compared to the UMTS alternative. The risk for the mobile WiMAX Network operator was identified as being high for the study period. As the Service operator had not so much investments, the risk was not so high. All in all, as there cannot be a WiMAX Service operator without a Network operator, this result indicated that there would not be any large scale WiMAX deployments in the Western European market, in spite of many speculations in public about WiMAX substituting UMTS.

The arguments about the superiority of the mobile WiMAX were demonstrated by the modelling to be based on a misleading overall view on the combination of technology parameters, technology development scenarios, market actors and market development. As some years passed from the publication of the first results in 2005 and 2006, it started to become more and more obvious that mobile WiMAX was not taking a major position as a ubiquitous 3G mobile solution in the Western European market. This development confirmed that the presented estimations were not justified. All the main mobile operators in Western Europe took the UMTS path, but mobile WiMAX deployments have been few and modest.

The realised 3G penetration rates and revenue levels related to the previous case studies were discussed thoroughly in Section 4.1.4. In Publications 3 and 4, the ARPU figures (average revenue per user) were derived for different segments by utilising the end-user modelling, so that the values, deviating from the earlier studies, did not include the termination fees gathered from other operators. These revenues, commonly calculated into ARPU, used to be substantial, but their importance is decreasing as the data services are making up a larger and larger part of the revenues. The termination fees relate mainly to operator’s own subscribers’ voice call termination to other operator’s network, and the End-user model gives hardly any differences between the technologies for the ordinary voice calls. The degreasing trend of the voice revenues is caused by the lowering tariffs.

The published ARPU figures are usually calculated by dividing operator’s revenues with the number of subscriptions, not subscribers. Therefore, as comparing the modelled ARPU figures that are estimated per *user* to the published ones, our figures have to be multiplied by the ratio of subscriptions to subscribers which might grow over 1,6 like in the Italy case, as referred to in Section 4.1.4.

The technology comparison studies suggested a sharp ARPU decrease for the users having only GPRS for data usage, as the voice service revenues were predicted to decline and even data service revenues not to grow much for GPRS usage (see Figure 30 in Section 4.2.2.2.). In these later studies even the 3G ARPU was not predicted to grow, but staying almost flat at the level of 40€ per month. In this case the data usage compensates for the decline in voice income (see Figure 31). Even though the increase in the number of subscriptions per user causes some confusion between the statistics, it is clear that due to the tariff erosion the revenue per low end, plain voice and SMS, user is decreasing, not to mention the revenue per subscription. It was discussed in the Section 4.1.4. about the possibilities of compensating for the reducing voice and SMS revenues by advanced services, and noted that thus far the operators, even with the 3G networks, have not been able to build up a flourishing 3G service ecosystem, with a compelling rich end-to-end experience. The OECD statistics show that the share of household spending on communications has had a decreasing trend after the year 2004 (OECD 2009).

However, the business case modelling suggests that the incumbent operators have a steady business position and good operating margins when taking all the utilised technologies into account. This has proven to be in balance with the operating profit reported by most of the major European operators throughout the studied years until now. The report by Capgemini TME Lab Analysis, based on Merrill Lynch, Global Wireless Matrix from April 2008, present operating costs of seven Western European mobile operations (six of them large incumbents, in six countries, two of which Nordic).

According to the report, the operating costs out of revenues were on average 54% in the year 2004 and 59% in the year 2007. This is in accordance with our modelling results for the Network operator business, where the average yearly operating cost estimated for the years 2007 – 2013 was 63% of the revenues of the UMTS/HSDPA operator (see Figure 34). In contrast, the estimated operating cost share for the Service operator in our model was on average about 80%, reflects the emphasis on the deployment and provisioning of the new value-adding services in the model. This deviation augments our previous observation that the Western European incumbents have not staked as much on the new services as in our model. Therefore, the revenues are lower, but the costs have been kept under tight control, ensuring profitability also in the current recession started in 2008.

The typical European mobile operator OPEX breakdown presented in the abovementioned section matches very much to our high level breakdown presented in Section 3.1.5 “Modelling of operating costs”. But, for example, when going to a more detailed level into the Network operator cost structure, there comes up many variations, depending on how the backhaul connections are implemented; through leased lines or own equipment, etc.

The results for the new entrants suggested a lower profitability and a high risk for the investment, even with new technologies like mobile WiMAX, compared to the steady position of the incumbents. This is probably the reason for few entrants having appeared on the Western-European market - except Hutchison 3G with a high risk taking capacity. Smaller entrants have however emerged, but in general the incumbents have dominated the market. The same has to be said about the MVNOs. The Dominance of the mobile incumbents and cautious competition between them, together with relatively low innovative risk taking until now, has kept even the MVNOs in a tight position.

4.3 Enhanced business case evaluation utilising real options

[Publication 5: Harno, J., Bedo, J-S., Katsianis, D. (2005b). Analysis of 3G mobile technology rollout alternatives using real options methodology. Proc. NAEC2005, Italy, Oct 2005, 15 pages.]

4.3.1 Background

New technology generations in mobile communications have until recent years been wide approaches; standards agreed on national, continental or even worldwide level. The generations named as 1G, 2G, and 3G have followed each other at about decade intervals, but now the picture has scattered, and many competing and complementing approaches are appearing with accelerating pace. Even in the former situation, especially forecasting of service demand, but also the technology development (or maturing) process, has been challenging, but in the current situation the assessment of the future business prospects has become even more demanding.

Telecommunications investment projects are traditionally analysed using depreciated cash flow (DCF) models. The DCF methods are based on one fixed view on the future development, upon which the calculations for the business cases are made. This involves in the current situation a significant risk of misleading results, as the scenario expected may fall short of being realised or become much more beneficial. The application of ROA is far from straight-forward in telecommunications projects, as the option concept derives from the world of marketed assets, but the investment project is based on intra company decisions, which are reforming the market. However, the real options analysis (ROA) method is an emerging tool helping to integrate to DCF method the flexibility in decision making as new information is revealed.

Although there have been some studies, where real options are applied on telecommunications investments (e.g. Alleman, 2002, Alleman & Noam, 1999, d'Halluin, Forsyth, Vetzal, 2002, Iatropoulos, Economides, Angelou, 2004), they have not been in related to full business case models. Benaroch & Kauffman (1999) provide a groundbreaking application of ROA to an IT investment project with real-like business case data, even though technologically and business-wise of a simple structure. There are certain features in their modelling that do not support full analysis of a more complicated case. In the ROA studies presented in this thesis, the value of the underlying project is based on the comprehensive operator model developed in the thesis' other case studies and it is based on large amount of revenue and cost related parameters, depending continuously on the time of the investment. The value of the underlying has to be calculated through separate model run for the points where the investments are made. It is thus impossible to use this value as a parameter in the Black-Scholes formula to calculate the option value.

To be able to use straight-forward Black-Scholes approach Benaroch & Kauffman, for example, model the yearly potential revenues as being fixed for each calendar year for the business actor, not depending on the starting year, assuming that the actor starting e.g. four years later than in another alternative will immediately get into the same revenues as in the early start case only after four years of operation. This is not in line with the most probable market changes and price evolution. In their case also the uncertainties (and thus volatility) of potential revenues are much related to one regulatory decision that may be resolved during the waiting period and thus would reduce the volatility. The Black-Scholes approach, however do not support changing volatility during the life of the option. In the thesis study, volatility is modelled based on demand development effected by multiple phenomena that probably cannot be fully resolved at any time the option is executable.

The lattice approach utilized in this thesis has also difficulties related to recombination of the branches, if changing volatility is needed, but there are some recent developments to cope with this (Haahtela 2010). The lattice approach enables, in contrast to Black-Scholes formula, also the usage of asymmetric volatilities, which result from many real world business case simulations, as demonstrated in Harno (2005a).

Tanguturi & Harmantzis (2006) analyse a mobile business case, but without analysis of all the related parameters, e.g. OPEX, and they do not derive the utilized volatility from the actual business case, but use the average industry value in stock market. They do neither model explicitly when the different investment decisions can be made and how their execution affects the revenue side.

Harmantzis & Tanguturi (2007) investigates UMTS and WLAN deployment cases as in some of the thesis studies utilizing real options. The study contributes to the ROA application in telecommunications, but also in it there are some deficiencies a more detailed techno-economic modelling like presented in this thesis is needed to cope with, as related to many real case challenges. For example, the modelling of subscriber amount, revenue and needed capacity in the UMTS case is coarse and straightforward and do not integrate the market related parameters or distribution of the different user types and their usage patterns. Also the capacity evolution of the technology is not taken into account. Therefore it is possible get very negative base case results, and the real option analysis does not change the case. In the thesis studies too, the ROA does not have effect on the results for deployment of UMTS into most areas, but the reason is not the cases being so negative, but the loss of revenues relating to the potential deferral.

The two last studies referred above use the Black-Scholes approach like Benaroch & Kauffman (1999), but contrary to them do not even try to take into account the lost revenues caused by a deferred deployment. All the studies referred contribute to the ROA application to different industries by providing simplified cases to demonstrate the possible real option analysis benefits. The thesis studies pursue forward to prove the applicability of ROA combined with comprehensive techno-economic analysis for large and complex real-world projects. This is demonstrated to require new approaches and methods in the ROA application.

The author has published or participated three real options studies, applying the binomial lattice approach, as described in Chapter 3, on 3G business case modelling:

1. The study “Real Option Evaluation of the European 3G Business Prospects” (Harno 2005a) analyses the economic impact of postponement of UMTS rollout in different area types by deferral real option analysis.
2. “Analysis of 3G mobile technology rollout alternatives using real options methodology” (Publication 5) performs ROA by investigating the value of the option to deploy UMTS into different area types, as an alternative to EDGE technology deployment.
3. "Analysis Of Technology Competition Between Emerging Beyond 3G Solutions" (Harno 2006a) investigates the value of the Network operator’s option to deploy UMTS as an overlay to the GSM/GPRS/EDGE network compared to an alternative technology approach with upcoming mobile WiMAX solution,. This case study demonstrates that it would be a valuable option for a potential WiMAX operator, to wait a couple of years to see the WiMAX market development and decide only then whether to go for a WiMAX or UMTS path.

4.3.2 UMTS rollout case study

Publication 5 investigates the value of the Network operator's option to deploy a UMTS network as an overlay to the GSM/GPRS network upgraded with EDGE. The value of this option, calculated without flexibility using the traditional depreciated cash flow (DCF) method, is simply the value of the project utilising UMTS overlay minus the value of the project without UMTS network. This value is calculated in the beginning of the project with the parameter assumptions at that moment.

The techno-economic model covers fully the cost structure of the operator as well as the demand, pricing and revenue issues. The DCF method is applied and the projects are calculated for a countrywide deployment. The discount rate used in the cash flow analysis for the projects is 10%. The modelled country demographics relate to a large European country with a population of 65 million inhabitants as in the previous case studies. The modelled operator is an incumbent operator having already a countrywide GSM/GPRS network and a 30% market share.

In this study, the two models for providing next generation mobile services utilising either UMTS or plain EDGE are divided into individual models for each area type, making eight models in total. The variation in the traffic generated by the users is estimated first. This reflects the market demand that is an unsure parameter. Introducing this variation to the models and using a Monte Carlo simulation generates a distribution of possible results (net present value) for the projects. From these distributions, we can calculate the "volatility" of the projects, and apply the real option analysis (ROA) method for each area for more accurate results than plain DCF analysis.

In this case study the network rollout is performed in four steps: first the dense urban areas are built in one year (2004); after that the urban areas are deployed in the next year (2005); followed by the suburban areas started one year later (2006), but taking three years to complete; the rural area rollout starts after that (2007), and takes four years to complete. The study period ends in the year 2011, after which the rest value (the remaining value) of the network is taken into account. The decision whether to deploy the UMTS in the ROA analysis is made accordingly in each year for respective area type taking into account the variation in demand that has generated different possible states of the world at these points of time.

4.3.2.1 Description of the case approach

The options are valuated using the binomial lattice method. For each option (dense, urban, suburban, and rural), the total NPV for UMTS and plain EDGE is evaluated each year, and can go down or up depending on the market demand. This evolution of the NPVs gives us a binomial lattice for each option. Options can be handled separately, as the decision on UMTS deployment in one area can be done independently from the decision for another area, due to the seamless handovers supposed between the technologies. It is though probable that UMTS is deployed in every state of the world most likely in the densest areas.

Traditionally the real option price is modelled as the investment needed in order to get the extra money from the project. In this case however, it is not possible, or it would be very difficult to model the investments explicitly. Firstly, the investments in the UMTS option are partly demand dependent, and demand is varied according to the state of the world (the traffic parameter). This could anyhow be coped with by expressing the exercise price as the UMTS coverage rollout cost, which is not demand dependent. In this study however, the UMTS rollout has an effect on the EDGE deployment, as part of the traffic migrates from EDGE to UTMS that provides the capacity more efficiently. So the only way is to model the option as a choice, in a particular state of the world, between the UMTS deployment in addition to EDGE and plain EDGE deployment. This option is valued as the expected NPV of the UMTS deployment minus the expected NPV of the plain EDGE deployment.

As not having the option strike price (investment) modelled explicitly we run into trouble, if trying to use the most widely used multiplicative (geometric) lattice, as it can never go negative. We need to use the additive process for the option value, which might go negative, when the lowest demand instances are realised.

The valuation is calculated in the ROA tree backwards to find out the ROA value of the option to deploy UMTS for each area type. Flexibility is implemented as the decision is made in the option exercise year if to deploy UMTS or not. The option to deploy UMTS is a European call option, as the exercise is in a definite year. If the UMTS deployment leads to a negative outcome the option gives the possibility to abandon the deployment.

In our implementation, the ROA tree utilises the risk-neutral probabilities and risk-free discount rate in the calculation of the option value. That is to say that the probability p for going up in the tree each year is computed utilising the risk neutral rule, and the value of each option is deduced backwards as the weighted value of the two option values corresponding to the consequent two scenarios (leaves). Annual risk-free discount rate 3% is used in the backward calculation.

4.3.2.2 Developed method

First we need to deduce the risk-neutral probabilities for an additive binomial lattice.

According to Copeland & Antikarov (2001), the risk-neutral probability approach starts out with a hedge portfolio that is composed of one share of the underlying risky asset and a short position in m shares of the option that is being priced. The hedge ratio, m, is chosen so that the portfolio is risk-free over the next short interval of tune. The hedge portfolio is riskless because if the value of the underlying risky asset goes down, so too does the call option written on it; and since we are short the call option, our wealth goes up. The loss of the underlying asset is offset by the gain on the short position of the call option.

As we have made the Marketed Asset Disclaimer (MAD) assumption (see the ROA method presented in Chapter 3) we can proceed by equating the end-of-period payoffs on the hedge portfolio, because if we can find the value of the hedge ratio m that equates the two, the portfolio will return the same cash flows in either state of the world. For the additive process the equation will get the form:

$$V_0 + u - mC_u = V_0 + d - mC_d$$

$$\Leftrightarrow m = \frac{u-d}{C_u - C_d}$$

Where V_0 is the starting value of the underlying, m is the hedge ratio, up movement of the underlying is denoted with u, and down movement with d. Correspondingly the option values in up and down states are C_u and C_d.

The hedge portfolio will earn the risk-free rate (r_f) and the resulting payoff will be identical to the up and down states. In the following equation we set the present value, multiplied by one plus the risk-free rate, equal to the up state:

$$
\begin{aligned}
&(V_0 - mC_0)(1+r_f) = V_0 + u - mC_u \\
&\Leftrightarrow V_0 - mC_0 = \frac{V_0 + u - mC_u}{1+r_f} \\
&\Leftrightarrow C_0 = \frac{V_0 - \frac{V_0 + u - mC_u}{1+r_f}}{m} \\
&\Leftrightarrow C_0 = \frac{V_0}{m} - \frac{(\frac{V_0}{m} + \frac{u}{m} - C_u)}{1+r_f} \\
&\Leftrightarrow C_0 = \frac{\frac{1}{m}(V_0(1+r_f) - V_0 - u}{1+r_f} + \frac{C_u}{1+r_f} \\
&\textit{by inserting } m: \\
&\Leftrightarrow C_0 = \frac{(C_u - C_d)(V_0(1+r_f) - V_0 - u)}{(u-d)(1+r_f)} + \frac{C_u}{1+r_f} \\
&\Leftrightarrow C_0 = \frac{C_u \frac{(V_0 * r_f - u)}{(u-d)} - C_d \frac{(V_0 * r_f - u)}{(u-d)} + C_u}{1+r_f} \\
&\Leftrightarrow C_0 = \frac{C_u\left(\frac{V_0 * rf - u}{u-d} + 1\right) + C_d\left(\frac{u - V_0 * rf}{u-d}\right)}{1+r_f} \\
&\Rightarrow \qquad p = \frac{V_0 * rf - u}{u-d} + 1 \\
&\textit{and} \quad 1 - p = \frac{u - V_0 * rf}{u-d}
\end{aligned}
$$

It can be seen that the risk-neutral probabilities up (p) and down ($1-p$) are dependent on the V_0 for the additive lattice, which means that the risk-neutral probabilities, up and down, are changing throughout the lattice depending on the value of the respective parent node. The only other parameters are the risk-free rate r_f, the up movement of the underlying, u, and the down movement, d. These risk-neutral probabilities are applied in the lattice implementations.

After the introduction of the calculation of the risk-neutral probabilities, the calculation of the volatility for the underlying V of the option will be focused on. The volatility (standard deviation) of the V, and thus the steps up and down in the lattice, are calculated from the volatilities of the UMTS and plain EDGE projects. If the initial value of the UMTS project is V_U and the plain EDGE V_E, the up movement of the V, u_V, is calculated from the up movements of the UMTS and plain EDGE projects, u_U and u_E as:

$$(V_U + u_U) – (V_E + u_E) = V + u_V = (V_U - V_E) + u_V$$

$$=> u_V = u_U – u_E$$

Similarly, the down movement of the option can be calculated as $d_U - d_E = -u_U - (-u_E) = -u_V$.

As the NPVs of the UMTS and plain EDGE projects upon which the option value is based, are calculated for a definite deployment schedule imposing certain time dependent costs and revenues, the underlying project of the option is not the same if started in the years before or after the determined exercise year, neither are the related investments. As the option's "strike price" (the investments, although in this treatment implicit) is time dependent, the use of American options is not possible. American options also presume that the exercise moment of the option does not affect the value of the underlying, which does not hold here.

To produce the value for the project volatility the variation in traffic generated by the users is investigated. For this a multiplier to describe the probability of annual change in the expected level of traffic generated by the users over the whole study period is introduced. This parameter is called the ServiceUsageMultiplier and suggested probability distribution (Minimum Extreme) based on expert judgement is described below in the context of the Monte Carlo simulation used.

The skewness of the distribution is justified by the fact that it is more probable to fall behind the predicted usage figures than to exceed them, as the network capacity would become a limiting factor in excess usage situations, either because of lacking incentive to upgrade it, or through the increased volume prices or volume gaps. On the contrary, if the usage does not start up in the market it is not so straight forward to boost it.

Eight modelled cases are analysed with Monte Carlo simulation to find out the NPV distribution as the ServiceUsageMultiplier parameter varies:

1) UMTS plus EDGE deployment in DENSE area
2) Plain EDGE deployment in DENSE area
3) UMTS plus EDGE deployment in URBAN area
4) Plain EDGE deployment in URBAN area
5) UMTS plus EDGE deployment in SUBURBAN area
6) Plain EDGE deployment in SUBURBAN area
7) UMTS plus EDGE deployment in RURAL area
8) Plain EDGE deployment in RURAL area

The Monte Carlo simulation (number of trials 1000, with random seed) is performed with the Crystal Ball^{TM} program, using Minimum Extreme (Gumbel) distribution for the ServiceUsageMultiplier (illustrated in Figure 40). The parameters for the distribution are:

Likeliest value:	1.00
Scale:	0.20

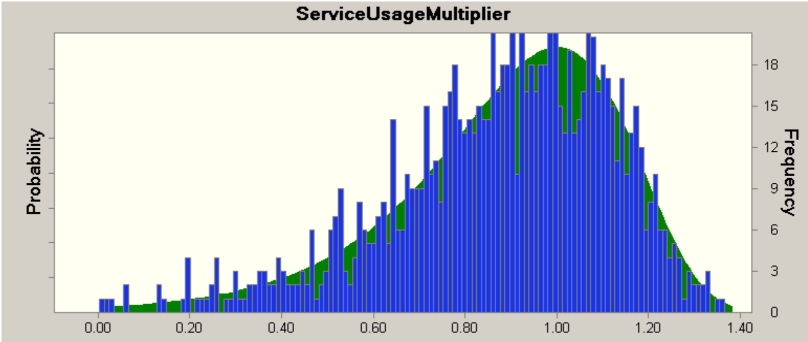


Figure 40: Distribution of the ServiceUsageMultiplier (Publication 5, from Crystal Ball™)

In the next table all the calculated NPVs distributions are illustrated.

Table 16: Main Results, All cases (all values in M€)

	Dense (UMTS)	Dense (EDGE)	Urban (UMTS)	Urban (EDGE)	Suburban (UMTS)	Suburban (EDGE)	Rural (UMTS)	Rural (EDGE)
Base Case	1 392	978	1 642	1 173	4 823	3 400	588	689
Mean	1 313	942	1 434	1 117	4 569	3 301	563	652
Std	204	141	401	196	896	625	409	352

4.3.3 Real option analysis results

The results of our valuation of the four options: Dense, Urban, Suburban, Rural can be now presented. The binomial lattices contain two figures for each node: the above one represents the evolution of the value of the underlying, i.e. additional value of the UMTS deployment (the difference between the NPV of UMTS and the NPV of plain EDGE), and the one below represents the evolution of the value of the option (calculated backwards using the risk-neutral probabilities and risk-free rate). The required parameter values are presented in Table 17. The value of the project in the year 0 has been calculated using the mean values and standard deviations for the UMTS and EDGE projects (see Table 16). The annual risk-free rate is assumed to be 3%.

Table 17: Input Parameters and Calculated results for all Areas (M€) (Publication 5)

	Dense	**Urban**	**Suburban**	**Rural**
Input parameters				
Value of the project in the year 0 (with no flexibility)	372	317	1 268	- 87
Life of the option in years	0	1	2	3
Annual standard deviation	63	206	271	57
Up movement per step	63	206	271	57
Down movement per step	- 63	- 206	- 271	- 57
Continuous risk-free rate per step	2.96%	2.96%	2.96%	2.96%
Calculated parameters				
Risk neutral probability up, in year 0	0.59	0.52	0.57	0.48
Risk neutral probability down, in year 0	0.41	0.48	0.43	0.52

In the following plots, the binomial trees of the projects of the different area types are illustrated:

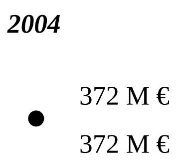


Figure 41: Binomial Lattice model of the Dense Area (no time window for flexibility) (Publication 5)

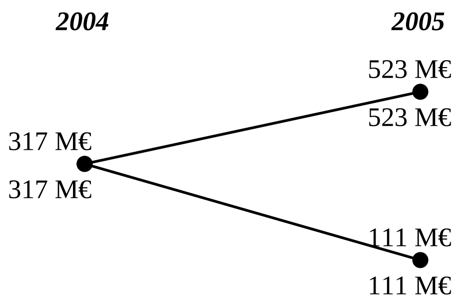


Figure 42: Binomial lattice model of the Urban Area (Publication 5)

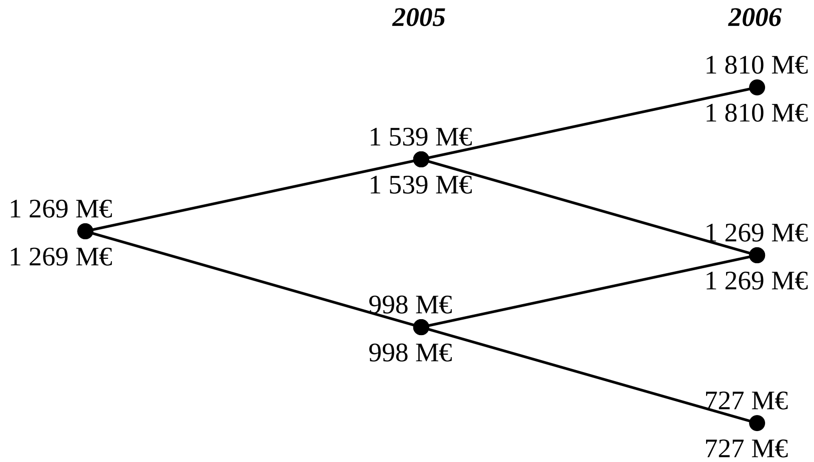


Figure 43: Binomial lattice model of the Suburban Area (Publication 5)

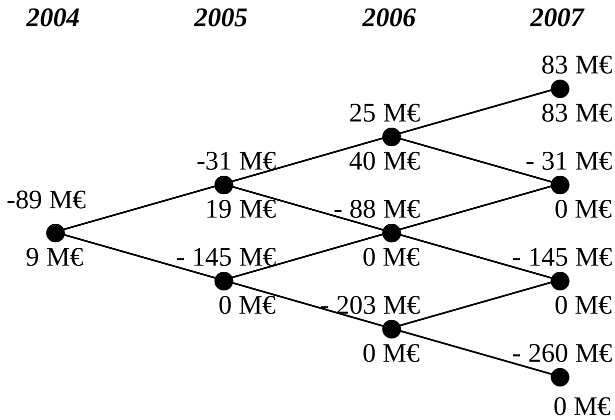


Figure 44: Binomial lattice model of the Rural Area (Publication 5)

4.3.3.1 Comparison with simulated decision tree approach

Also another method than finite binomial lattices has been used to valuate the Rural option for comparison. The idea is to generate a big number of branches in the decision tree by using a Monte Carlo simulation and to utilising the probabilities of realisation of the different scenarios directly (without the real option calculations).

We model the difference V_y between the NPV of UMTS and the NPV of plain EDGE at the year y by a normal distribution with a mean of V_{y-1} and standard deviation equal to the volatility of V_0. As a result, at each step of the Monte Carlo simulation, we simulate the values of V for each year between 2004 and 2007. Then, we evaluate the condition $V_{2007}>0$ and, if it is true, the option is valuated to the level of V_{2007}, otherwise the value of the option is zero. We present below the distribution of the value of the option for a run of 10 000 simulations.

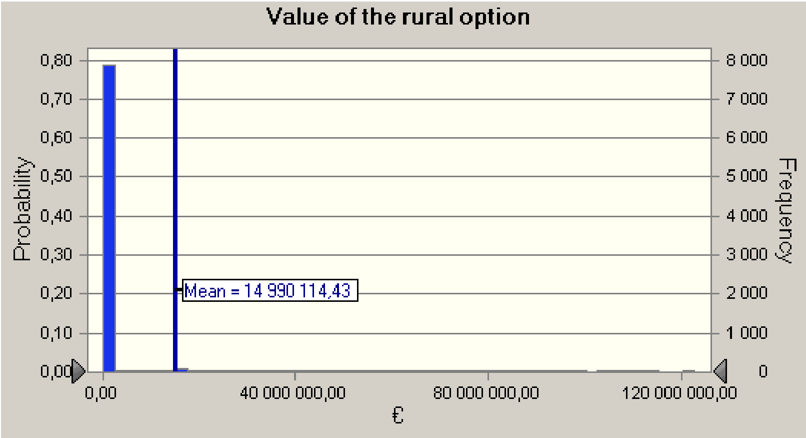


Figure 45: Value of the Rural option (Publication 5)

It can be seen that the mean value of the option (~15M€) is higher than the value obtained with the option calculation using the lattice method. This is partially due to the equal probability to go up or down in this case compared to a higher probability to go down with the risk-neutral probabilities of the real option analysis lattice method. Nevertheless, the probability to have an option value greater than zero is very low. This approach also lacks the discounting of the option value when deriving its present value, giving somewhat too high values.

In addition, a correlation of 0.8 has been put between the up and down movements of couples of the consecutive years (V_{y-1} and V_y) and a mean option value of 46 M€ obtained. It is assumed here that the situation in one year depends on the path followed by the value of the asset. As a consequence, a correlation exists between V_{y-1} and V_y and should be taken into account. This correlation is increasing the kurtosis of the distribution and thus increasing the option value. The highest incurred values are far from realistic.

The autocorrelation in volatility leads easily to a high amount of total failures and thus an early stop of the project, as well as unrealistically good outcomes, as can be seen in Figure 45. As we are here dealing with anticipated parameter values (of e.g. demand) before the actual business realisation, the “loose” volatility with no correlation between the consecutive years seems thus a more realistic way to model the volatility also with real options, corresponding to the randomly fluctuating prices in the stock market.

4.3.3.2 Comparison with DCF analysis

As assessing the potential value of a project under uncertain conditions, the mean value of the NPV provides better information than the plain expected value, providing that the variation distribution of the parameters gives more information than the plain guess for the most probable outcome.

It can be seen that the traditional DCF analysis, with no distinction on different areas, gives the least accurate information for the basis of decision on the approach - with or without UMTS in this case. It does not take into account that even though UMTS is a valuable project, better results are attained, when plain EDGE is deployed in the rural areas. The value of the option to deploy UMTS is calculated as a whole, but is the same as the sum of the area projects:

(1 313 - 942) + (1 434 - 1 117) + (4 569 - 3 301) + (563 - 652) = 1 868 M €

The area specific techno-economic analysis reveals that the probable value of the rural area UMTS deployment is negative, so that only EDGE is to be deployed there. This analysis gives a bit better value for the option to build UMTS:

(1 313 - 942) + (1 434 - 1 117) + (4 569 - 3 301) + (0) = 1 957 M €

The real option analysis, taking into account the flexibility to make the decision later, based on the information available at that moment, gives the best basis for judgement, and in this case the highest value for the option. The difference results from the fact that the investment for UMTS is done in the most favourable demand situations of the exercise year, but only in that situation:

(1 313 – 942) + (1 434 - 1 117) + (4 569 - 3 301) + (9 054) = 1 966 M €

4.3.3.3 General case findings

A new framework for communications infrastructure investment projects, based on real options, is presented and analysed in Publication 5. It has been shown that real options analysis can and should be taken into account in the complex technology deployment projects. Real option pricing should be a complement to existing capital-budgeting systems and not a substitute for them.

Although the ROA did not make a remarkable difference in the UMTS option value in this case study, it nevertheless provides the most accurate method to calculate the value. On the other hand, these results demonstrate that in large technology projects, the value of flexibility might not be necessarily as high as sometimes suggested when promoting the new methodologies. In many ROA studies, it has been suggested that the investment relating to the exercise of the real option is a fixed amount of money that can be paid at a certain point, not depending on the changing state of the world and its effects on the business. In reality, the technology investment is dynamic and dependent on the capacity demand, and generates different life-time revenues depending on the time of the takeoff. Neglecting these factors leads easily to exaggeration of the benefits from postponement. Also, there is in most cases an alternative for a technology investment, so that the alternative for the particular investment is normally not to be totally passive, but to invest into another technology deployment. Like in this case study we have the plain EDGE deployment as an alternative. Here we have, in addition, taken into account that if circumstances develop favourably for one technology alternative (UMTS), they develop in this case so for the other alternative (EDGE) too, though with a different rate.

On the other hand, the yearly potential variation in demand level can be higher than suggested in this case; especially in cases, where delay in demand, related to any technology solution provided, can be anticipated to be probable. This may lead to higher ROA values for options to postpone the investments. Secondly, if demand is very much related to a certain technology alternative and the competition is still underway, the option value of the winning technology project would grow high compared to the competitor, resulting probably in higher a ROA impact than in this case study.

One analysis topic could have been to investigate the postponement of the UMTS decision for different areas. The lattices introduced cannot be extended to look for the option value, if the exercise would be in the following year. This is because the UMTS and plain EDGE project values and volatilities are calculated for the specific decision point only. If the rollout is carried out one year later the project model would give completely different net present values, due to different revenues and build-out costs. In general, the NPV results of the studied projects decrease in the case of postponement, due to lost revenues, so in current cases the impact of postponement option seems to remain low. But as mentioned above, in some other contexts, the postponement and alternative technology options may provide interesting further study topics relating to the benefits from ROA.

4.3.4 Assessment of the real option approach

The case studies show that the developed real option approach will give deviating results from DCF, as taking the flexibility into account in choosing the most feasible technology deployment. However, the results are not radically different, and bring up changes only in specific situations, but reduce back to the DCF results in most parts. This gives assurance that real options are not a theory that gives questionably different results from the traditional, but an important supplement for the familiar DFC method to increase the accuracy in the investment project valuation.

ROA can lead to wrong suggestions for postponements, if the lost opportunities for early revenues and acquired market position are not properly taken into account in the modelling (Harno 2005a). The ROA method should be applied in an explicit way, as there is always the danger that it is applied too theoretically, not taking into account the limitations or dynamics introduced by the particular business case. Most of the industry projects deviate so much from the stock market realm, that many of the assumptions are not valid. Although the market changes stochastically, investments to real projects are unique competitive opportunities, where postponement costs in lost revenues along the project time window. Both of these aspects have to be combined in the real option modelling. If the projects are properly valuated, taking the former into account, their prices can be assumed to fluctuate randomly according to the volatility that is related to the relevant market parameters, and real option calculation can be utilised.

Often with real options the information is not increasing with time without investing – contrary to the stock options. This is emphasised especially in cases, like often in communications, where the infrastructure (e.g. network) has to be built before the product or service can be launched. In the modern technology cases also test marketing and even market studies do not give good information about the option, as it is a question of total end-to-end experience with high network effects.

This can be interpreted to be one reason also behind the early UMTS launch phase and especially the mobile service market wait-and-see situation, where the market actors are waiting for the market “option” to mature before acting, i.e. before making any heavy investments. This trend is strengthened if several actors are needed to build the market where others can easily follow after its maturing, and where the business position is hard to protect with IPRs or otherwise control the value network. For UMTS launch, however, the network investment was an extensive long haul project taking time to be completed, thus protecting against fast followers and giving a certain time window for charging customers, but after that phase the added-value service provisioning offers a more complicated modelling challenge real option wise too.

4.4 Impact of fixed-mobile convergence

[Publication 6: Harno, J., Kumar, K.R.R., Heikkinen, M., Kind, M., Monath, T., Von Hugo, D. (2009b). Service Offerings for Fixed-Mobile Convergence Scenario: An Integrated operator Case. *International Journal of Business Data Communications and Networking (IJBDCN*), Volume 5, Issue 3, pp. 1-16.]

4.4.1 Background

The next generation services delivered via fixed-mobile converging (FMC) networks have been under discussion and consideration for several years. Though concepts and experimental implementations are widespread, truly operational experience is still lacking. Various actors in the communications value network follow different definitions of the FMC concept. Convergence may start either with common device providing access to both fixed and mobile networks or with a common billing and customer care centre offering the user one-stop shopping. Various stages of convergence may be achieved on the access and core network technology levels, management, service enabling and content and application level with an operator's own or shared platforms.

In Publication 6, FMC is broadly defined as the end-to-end provisioning of unified services accessible by the end-user independent of the underlying access and core network technologies. To enable an efficient realisation of such an ecosystem, convergence has to occur at multiple levels, namely at the network, service, device and commercial level. One major enabler to achieve a seamless interconnection between all entities included in this picture is the use of a common underlying protocol infrastructure which nowadays still seems to be the Internet Protocol (IP). An overarching control platform for both services and underlying resources and transmission capacity is the IP Multimedia Subsystem (IMS) as standardised and agreed on in both fixed and mobile standardisation organisations.

The study elaborates on a migration concept for an integrated operator from current separated traditional fixed and mobile networks towards FMC and IMS at different levels of service provisioning. The model investigates the impact on the overall profitability. The investigation considers different actors in the FMC ecosystem: the operators of access and core networks, service and content providers, hardware and software manufacturers, vendors and legal authorities. Key drivers for industry development, for technology evolution and market demand are taken into account.

The study demonstrates that an integrated operator can benefit from cost savings, customer retention and prevention of revenue erosion by an FMC migration strategy with the introduction of advanced service packages. This development is driven by the increasing importance of mobile network capabilities and services, as well as the lessening gap between fixed and mobile systems, in terms of technological models and prices. The result will be greater market-pull and commercially feasible FMC offerings. FMC is expected to offer benefits for network and service operators as well as businesses and consumers.

There have been published some telecommunications convergence studies concentrating on certain service or type of service, like television and multimedia (Rangone &Turconi 2003) and telephony with dual mode fixed wireless / cellular mobile phones (Pretorius, 2009). It can be found also a broader market analysis of FMC in Taiwan (Lee 2007). The study presented here is, however, the first quantitative full business case modeling of integrated operator to go for FMC. Many findings in the referred studies are in line with our results. The author of the thesis has authored or co-authored several journal and conference articles relating to techno-economical modelling of 3G convergence scenarios, the last one of which is included to the thesis (Harno 2007b; Rokkas et al. 2007; Rokkas et al. 2009; Harno et al. 2009b). The delta analysis approach is a new approach in the field of communications techno-economics, and suits exceptionally well to the business situations, where decision has to be made on two alternatives that are partly coincident.

4.4.2 Fixed-mobile convergence model

The operator's dilemma is analysed by selecting an appropriate migration strategy to exploit the benefits of cost savings and generating new revenues, while exposing oneself to the risk of substitution effects among its fixed and mobile products. The objective in this study has been to provide quantitative comparison of some strategic scenarios utilising techno-economic case study method to model the delta costs and revenues between the FMC approach and non-FMC approach for a major integrated operator in a "Large" -type country in the Western European context (see Chapter 3 for country characteristics). Its initial market share is 40% for mobile telephony, 60% for fixed telephony and 50% for broadband.

As Publication 6 concentrates on the delta comparison, the absolute values of the revenues and costs are not presented, but the aim is to give an estimate of the differences of the two approaches for a major incumbent actor. This requires, however, modelling of the total customer base and related revenues and costs for both approaches. The absolute values of the general OPEX and investments in any case need not be strictly modelled, but the average level is enough, as the starting point is the same for both. On the contrary, the FMC specific investments and OPEX effects, as well as the effects on customer base and revenues per different subscriber segments require careful modelling. The resulting delta figures should be proportioned to the general results of a market actor of the position described, with generally over 10 B€ annual turnover.

4.4.2.1 Motivation and strategic considerations of integrated operators

An integrated operator is characterised as the owner of both fixed and mobile networks in a market, initially having a clear separation of the fixed and mobile operations' business units, i.e. each having its own customer care, marketing, subscription management, network and service provisioning units. Traditionally, an integrated operator has been one of the incumbents in the market, often having a leading market share. Figure 46 illustrates some of the major reasons for an integrated operator's interest in migration to FMC from its existing situation.

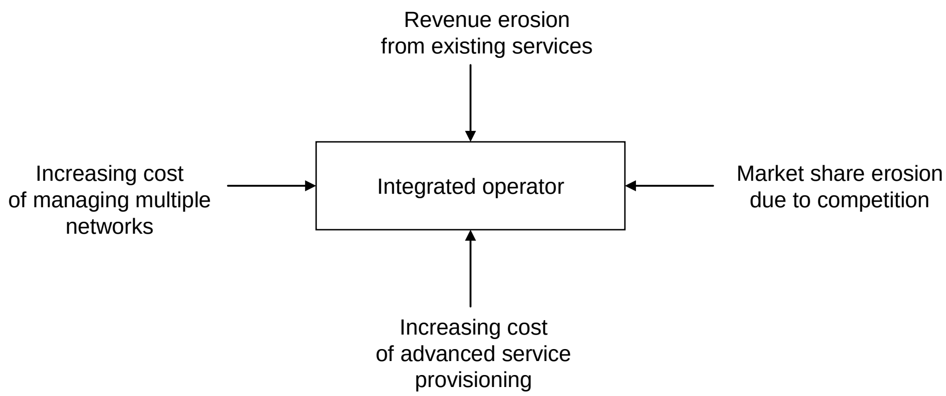


Figure 46: Issues in an integrated operator's business (Publication 6)

In order to solve the issues mentioned in Figure 46, the integrated operators have motivation to deploy FMC, which will enable the provisioning of advanced multimedia services easily and efficiently with a shorter time-to-market across multiple access networks (with a common IP-based core network). Such services are expected to retain the loyalty of customers, reducing the churn and generating new sources of revenue. However, the provision of a full FMC service portfolio also introduces new risks and challenges to a traditional telecommunications operator. New FMC services may substitute existing profitable products and thus cannibalise an operator's business case.

4.4.2.2 IMS architecture and dimensioning

The IP Multimedia Subsystem (IMS) combines fixed and mobile cores and provides common mobile and fixed services. IMS is generally accepted to deliver carrier grade SIP-based session-oriented applications, including voice, dual-mode/FMC, unified messaging, presence, video sharing, enterprise integration (e.g. IP Centrex, Mobile PBX, Hosted Call Center), online and mobile games, group chat, and push-to-talk/push-to-video. The IMS architecture has been described in Figure 7 in the Technology architectures chapter above.

One of the main tasks of the IMS part of the FMC model is to calculate the annually required capacities for each IMS component, thereby determining the number of each IMS components required for the rollout, i.e. the shopping list, as shown in Figure 47. The main variables affecting the shopping list are service usage and the number of FMC subscribers. Usage translates into three technical dimensioning parameters which will be elaborated later. The number of subscribers is dependent on population, IMS compatible device penetration, IMS service penetration and operator market share.

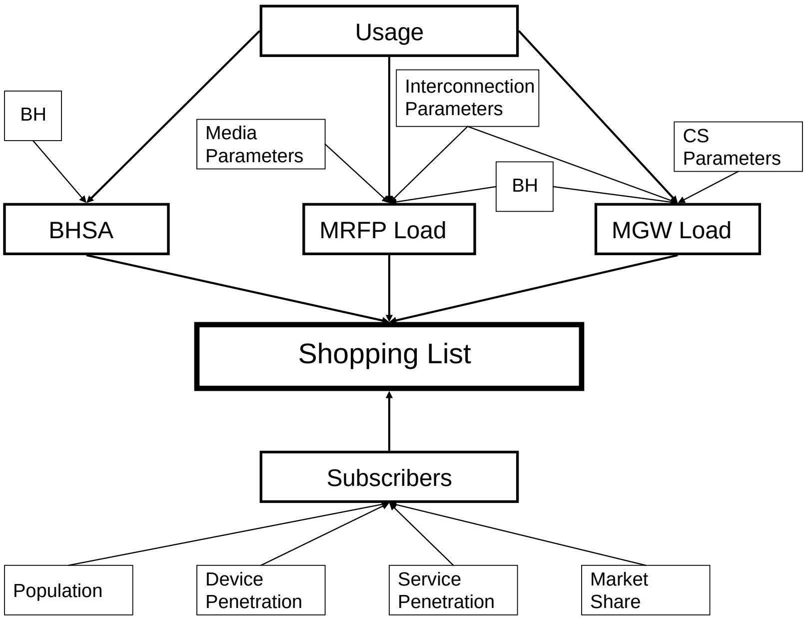


Figure 47: IMS dimensioning general structure (Publication 6)

The input data used in dimensioning is based on insight within the study project, six open semi-structured expert interviews conducted during November and December in 2006, analysis of IMS products from 11 vendors, and several academic, analyst and industry sources.

The dimensioning rules and the included functions of IMS components are presented in Table 18 based on expert opinions and IMS product analysis. The reference prices are for the year 2007, VCC (Voice Call Continuity) being an exception with the reference year 2009. The components are subjected to price erosion defined later.

Table 18: IMS components' dimensioning

Comp.	Capacity	Unit	Included functions	Price (€)
AS	2 500 000	subscr.	Generic Appl. Solution	2 200 000
CSC	2 000 000	subscr.	P-CSCF, I-CSCF, S-CSCF, BGCF	3 000 000
	2 000 000	BHSA		
HSS	2 500 000	subscr.	HSS, SLF	1 100 000
MGC	2 000 000	subscr.	MGCF, SGW	800 000
MGW	25 000	ports	IM-MGW	2 300 000
MRFC	2 000 000	subscr.	MRFC	600 000
MRFP	1	Gbps	MRFP	2 400 000
SF	2 500 000	subscr.	BGW, IBCF, TrGW, BSS	900 000
VCC	2 000 000	BHSA	CCCF, NeDS	800 000

BHSA refers to Busy Hour Session Attempts. It is calculated from service usage by applying session attempt (SA) and busy hour (BH) multipliers to the usage data. For a call, 1.0 SA is assumed. Other service dimensioning units are related to it: a message 0.5 SA; a presence update 0.2 SA; and a service setup 0.9 SA. BH usage is estimated to be 20 % of total usage. For the VCC component only VCC related call usage is taken into account.

The ports number used with the MGW component refers to simultaneous CS calls processed. For calculating that, CS voice penetration and CS call interconnection rates are assumed. The final result is derived for the BH using Little's formula (Durrett 2001), with a uniform distribution and average call lengths.

The MRFP component employs an actual data transfer capacity. It is used for audio and video conferencing, network announcements, and voice mail. Estimates of shares of calls, average session lengths, data rates, and occurrence probabilities are used to yield data volumes. The end result for the BH is derived similarly as in the MGW case.

The IMS media and interconnection parameters, i.e. parameters related to MGW and MRFP, are presented in Table 19. They are derived based on expert opinions and standards like TS 26.236 (3GPP 2009). For both audio and video conferencing, 3.5 users are assumed per conference with a 39 kbps stream for audio and a 74 kbps for video per each user. Announcements and voice mail are played with a 39 kbps stream. The call interconnection departure rate is the number of calls departing to other networks out of the total number of calls. The call interconnection arrival rate is related to the number of calls arriving from other networks.

The number of subscribers is a multiplication of population, IMS device penetration rate, IMS service penetration rate, and operator market share. Table 20 depicts other IMS time dependent parameters based on a large set of analyst reports and studies, combined with in-project expert judgement (ARCEP 2005; Bundesnetzagentur 2005; Capgemini 2005; Informa 2006; International Game Developers Association 2005; Ofcom 2006; RealNetworks 2005; Strategy Analytics 2006; UMTS Forum 2003; Verkasalo 2007). The CS voice penetration rate is used in MGW traffic calculations. The VCC penetration rate is utilised in load calculations of the VCC component. The component price erosion depicts a common falling price curve for the IMS components. The usage figures are on per user per month (PUPM) basis and combine both downlink and uplink usage.

Table 19: IMS media and interconnection parameters

Voice conference share (% of calls)	0.1 %
Voice conference average length (min)	30
Voice conference data rate (MB/min)	1.02
Video conference share (% of calls)	0.05 %
Video conference average length (min)	30
Video conference data rate (MB/min)	1.94
Announcement probability	10 %
Announcement average length (min)	0.2
Announcement data rate (MB/min)	0.29
Voice mail probability	5 %
Voice mail average length (min)	0.5
Voice mail data rate (MB/min)	0.29
Call average length (min)	1.50
Call interconnection departure rate	50 %
Call interconnection arrival rate	200 %

Table 20: IMS time dependent parameters (Publication 6)

	2007	2008	2009	2010	2011	2012	2013	2014
VCC penetration	0 %	0 %	50 %	45 %	40 %	35 %	30 %	20 %
Component price erosion		-10 %	-5 %	-2 %	-2 %	-2 %	-2 %	-2 %
Calls (PUPM)	230	234	238	242	245	250	249	252
Messages (PUPM)	48	71	89	110	126	144	166	189
Presence updates (PUPM)	48	101	184	268	330	372	389	413
Service setups (PUPM)	6	10	19	32	49	71	91	107

4.4.2.3 FMC Service offerings

Modelling of the offered services and service bundles is an essential part of the scenario description. The starting point for the FMC products is a converged voice product, which is enhanced over time with converged data services. The FMC integrated operator will initially offer four options for the customers: the FMC Bronze, Silver, Gold and Platinum packages (shown in Table 21).

Table 21: FMC services (Publication 6)

	Voice (mobile/fixed unlimited national calls)	**Fixed BB Internet**	**Mobile data quota per month**	**Initial tariff per person per month**
Bronze	+	+	0	45 €
Silver	+	+	20 MB	50 €
Gold	+	+	200 MB	69 €
Platinum	+	+	2 GB	93 €

Figure 48 illustrates the distribution of users that will use the FMC products, among the different offered packages. In addition to the components mentioned in Table 21, each of the above packages also include some FMC services (e.g. free access to Wi-Fi spots, VoIP, instant messaging etc.) as part of the bundle. The reasoning behind such free FMC services in the early stages of FMC introduction is to attract customers to these packages. The monthly revenue per FMC customer is calculated as the sum of the separate subscriptions (fixed voice, mobile voice, fixed BB and mobile data packet) minus a reduction of 10%. In addition to this, the price of each FMC package in Table 21, as well as the non-FMC service is assumed to decline by 5% annually. Such a price cut by as much as 15% in three years has been expected for some time (Exane BNP Paribas & Arthur D Little 2006).

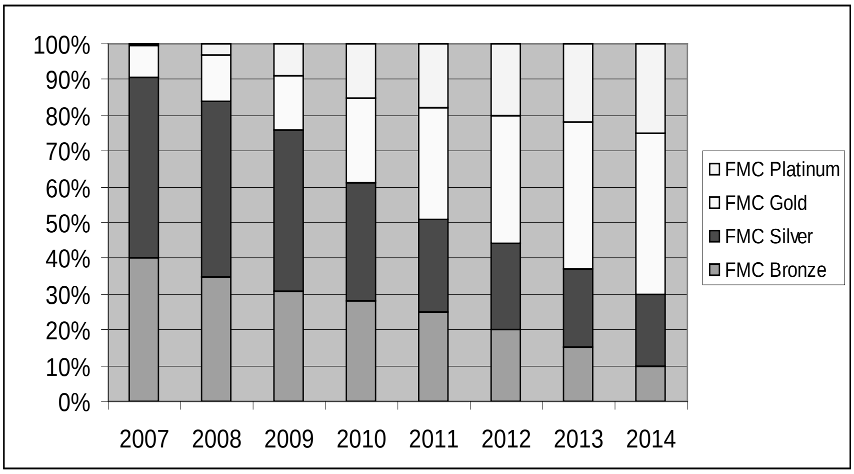


Figure 48: Services distribution (Publication 6)

Upon these package based monthly fees, the FMC customer can subscribe to certain new services for an additional fee. All these additional services are presented in Table 22.

Table 22: New and substituting FMC services

FMC Services	**FMC Service Enablers ("x" represents the potential utilisation for enhanced services)**			**% of customers adopting FMC services during study period**		**Service character**	
	Location info	Presence/ Profile	QoS	2007	2014	New	Substitute
IM	x	x		2	30		x
VoIP	x	x	x	1	50		x
IP/mobile TV	x	x	x	0,5	15	x	
Network Gaming	x	x	x	0,5	20	x	
VoD			x	1	25	x	
Unified data access	x	x		1	50	x	x
Community-based services	x	x		1	50	x	x
Unified Communications	x	x		1	17	x	

Publication 6 makes a differentiation among FMC services into a category of completely new services (such as IP/Mobile TV, Unified communications), not fully available in the separated non-FMC networks, and into IMS-based services (such as IM, VoIP) that potentially substitute the classical ones and thus cannibalise the operator revenues. Cannibalisation means that customers adopting IM service partly skip the use of traditional SMS, and usage of VoIP will reduce the CS voice revenues. However, e.g. SMS is still utilised to reach those users not yet migrated to IM.

Also usage of community-based services (groups, social networks, blogs, etc.) will have some impact on existing messaging, with raising effect on usage even for those still participating through, for example, SMS-IM gateways. Unified Communication (i.e. offering all person-to-person communication services with single-sign on) will primarily be focused on business customers, adding value to the current person-to-person offerings (AT&T 2008). Growing demand has been identified for location information by major market researchers (e.g. Gartner 2006; Juniper 2006; Canalys 2006; Canalys 2008). Location information, together with enhanced profile and presence information, increases the convergent service possibilities, both communication and content related. Improving interaction and communication between different electronic devices, over the air, increases further the benefits and attractiveness of the FMC offering.

Expected additional monthly revenue for the FMC operator is 10 € per subscriber of the new FMC services together (excluding Unified Communications) and 10 € for Unified Communications (intended mainly for the business customers). Unlike the FMC packages previously mentioned, no price erosion has been assumed for these new FMC services due to increasing customer value during the study period. We have assumed a 30% operating profit margin for these services. The new services will have an impact on transport costs, but assessing the current packet based network and radio technologies development, we estimate that the services can be provided feasibly in the framework of the mobile data quotas introduced in the packages above. The investments in core IMS are calculated through the IMS dimensioning procedure presented above. In addition to that, investments for additional enablers, like application servers and support systems, are estimated to be 70 M€ per 2.5 M FMC subscribers during the study period.

4.4.2.4 OPEX considerations

The operational expenditures for an integrated operator can be divided into seven general categories listed and described in the following:

- Network related elements: includes all the necessary costs for network operation, OSS operation, maintenance and repair of the network elements, equipment and software licenses, rental of network resources, costs for site rental and electricity.
- Interconnection and roaming costs: termination fees for calling or completing a call or a session originated or terminated in another network.
- Marketing and sales related elements: costs including advertisement, customer acquisition, SLA (Service Level Agreement) negotiation and subsidisation.
- Customer service related elements: costs associated to customer care and CRM (Customer Relation Management) operation.
- Charging and billing: includes traffic metering, accounting and controlling.
- IT and general support related elements: includes Business IT, management support, and costs regarding the purchase of licenses for content delivery.
- Service development related elements: includes new service related market research, design and development as well as integration to operational and business support systems for provisioning, management and monitoring.

Costs within these categories have only been considered here in case they are affected by a potential operator decision for migration to FMC - in terms of savings and additional expenses affected by the FMC decision:

- Costs related to network elements and interconnection and roaming will generally be reduced for a convergent network with less elements and a common management system.
- Marketing and sales, customer services, and IT and general support related elements are characterised by additional effort in the beginning, e.g. in terms of processes for and advertisement of the new FMC subscription, whereas towards the end of the study period savings thanks to unified products and a single interface towards the customer will occur in the FMC case.
- Marketing and development of services will become cheaper as the same services for both mobile and fixed systems have to be considered only once.

The results of the break-down of OPEX savings is shown in Figure 49 below.

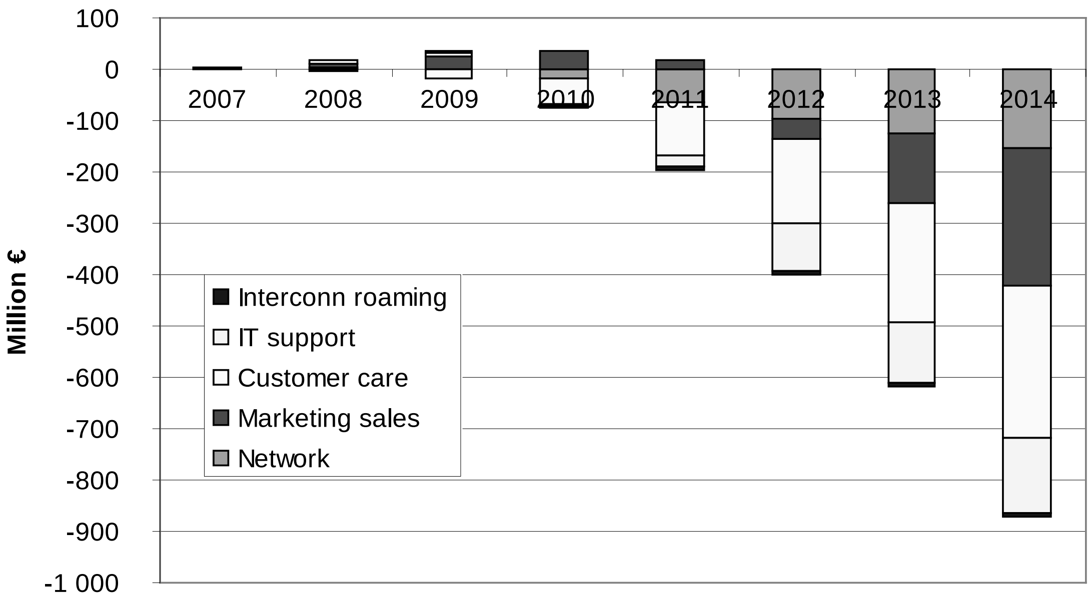


Figure 49: FMC case OPEX (delta) breakdown (negative values show OPEX savings) (Publication 6)

4.4.2.5 Market modelling

The country type considered for the market modelling is the "Large Country" in Western Europe such as France, Germany, Italy, or UK. (The country characteristics are described in Chapter 3). The study period is 8 years, starting from year 2007. The integrated operator has a strong market position in the beginning: 60% in fixed telephony, 50% in BB and 40% in mobile. Fifty percent market share of converged customers is assumed, if entering the FMC path. If not, it is estimated that half of the potential FMC subscribers are lost.

The FMC offering can also lure new customers, but this has not been considered here. The basic assumption relating to competition has been that, if going for the FMC services the incumbent can keep its market share, but if not, the competing offerings will erode its customer base, usage figures and revenues.

For the FMC case, the potential for integrated FMC customers is estimated from the penetration of IMS capable devices and IMS service demand. Although the break through is expected by the UMTS Forum to take place only after 2012 (UMTS Forum 2005), in our case where the operator strongly promotes FMC and IMS, more steady growth from the beginning is assumed (see Figure 50).

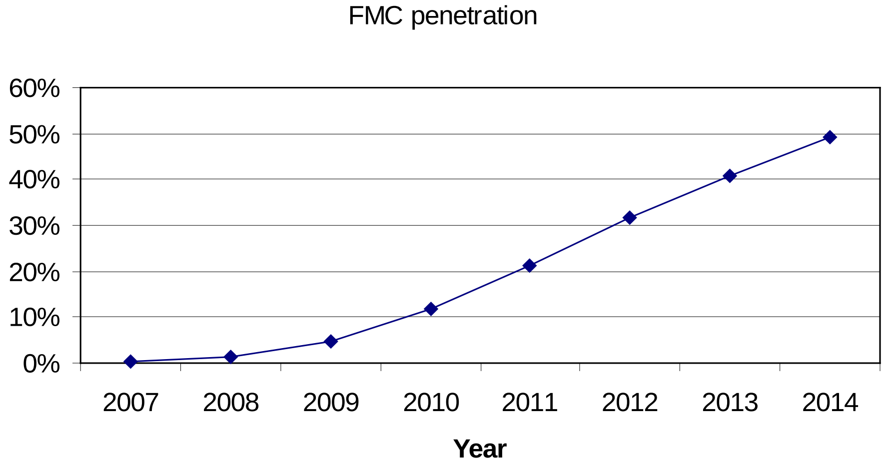


Figure 50: Penetration of convergence customers for the FMC case (Publication 6)

The analysis in this scenario focuses on calculating the effect of the integrated operator's decision, whether to migrate to FMC or not, on its overall business. This means that only the differences (i.e. delta) between the non-FMC and FMC (network and service) case are considered. Revenues and costs that would exist regardless of FMC are not treated separately. At the beginning of the study period the operator has two options: either he will implement FMC, begin the installation of the various IMS elements needed and start offering new services or continue with the existing condition, meaning, the operator will continue to own two different networks.

4.4.3 Convergence case results

The advantage of the FMC approach for an integrated operator is demonstrated in Publication 6 as the delta difference between an FMC-driven strategy and the expected development for a non-FMC scenario. This delta will show up in the operators' additional FMC related investments and additional operational expenditure (OPEX). The FMC approach affects also the market share and service demand figures, reflected in delta revenues related to both factors. In addition, the new convergence services add new profit streams to the business case. A cash flow comparison over the study period is provided in Figure 51.

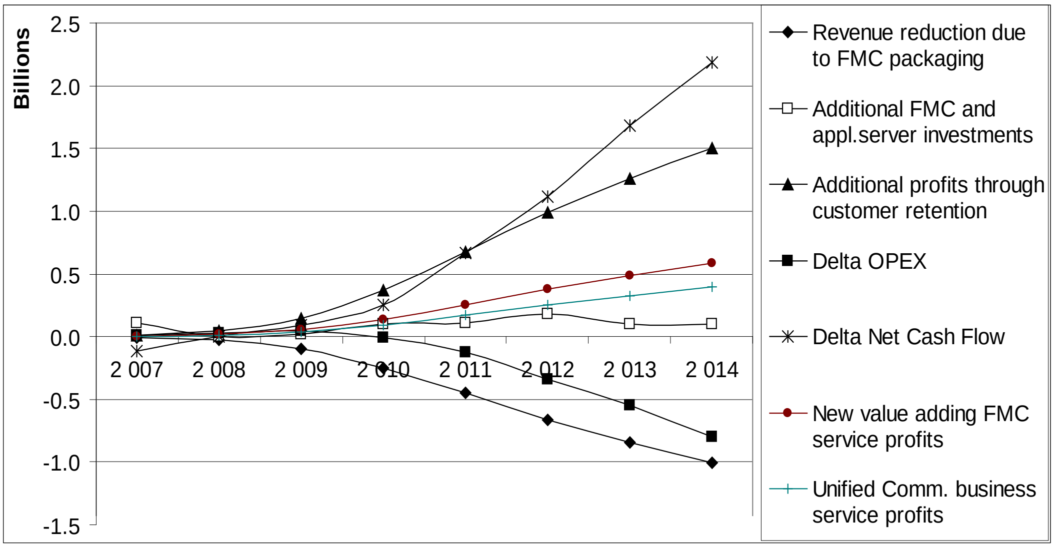


Figure 51: FMC case cash flow effects for the integrated operator (Publication 6)

Application servers and the IMS related PS signalling and CS-PS gateways are the main sources of additional (delta) CAPEX for an integrated FMC operator. However, there are many sources of cost uncertainty dependent on the existing architectural structures of the operator. These include support function upgrades, service realisation aspects and service usage. The extent of required business support system (BSS) updates due to IMS will be highly dependent on operator and service requirements. Operators with outdated legacy systems will face higher additional costs than operators with up-to-date systems.

Compared to the estimated rather small FMC-investments, 721 M€ over the whole study period, related to the FMC customers (without considering the network migration towards IP) there is a high OPEX saving potential for the FMC operator.

At the end of the study period, the yearly OPEX savings due to convergence are estimated as substantial, over 800 M€ in 2014, which is about 7% of the total yearly OPEX of the operator (see Figure 49 above). From the results, it can be seen that after some years, the operator will reduce its OPEX compared to the non-FMC situation. The trend in the OPEX savings is growing even after the study period, giving a considerable competitive advantage for the integrated operator selecting the FMC path.

Major contributors to overall OPEX over the entire study period, are customer care (40%), network maintenance and management (19%), IT support (15%), and expenditures for marketing, sales, and customer acquisition (12%). Roaming regulation and expected interconnection models for IP networks are still uncertain and may not differ very much from the non-FMC situation, whereas figures for marketing will increase in the beginning as new products and services have to be established. The saving increases towards end of the study period because a concentration towards converged products will occur. Similarly, the customer care effort will be reduced because of less separate subscriptions within the integrated converged network compared to two separate networks and multiple subscriptions per person.

If going for FMC, the operator is estimated to lose revenues, since the tariffs of the new products should have a discount compared to the sum of the mobile and fixed tariffs in the non–FMC case.

On the other hand, it is estimated that if the integrated operator does not invest in FMC, it will start losing customers to other operators that are driving FMC. The estimation is that in the non-FMC operator case the market share in all sectors, mobile, fixed voice and BB goes down due to competition and lower price bundles offered by the FMC operators. This is estimated to have a significant positive effect in the long run, even a yearly impact of 1500 M€ in the end of the study period. The combined impact on profitability by these revenue streams sums to 500 M€ yearly delta net cash flows in 2014, as taking into account also the negative revenue "cannibalisation" effect of the lucrative product bundles (see Figure 51 above).

Being in a strong position to provide the new services for its converged customers, the FMC operator is estimated to produce additional profits in the residential and business markets with total value growing up to almost 1000 M€ in the year 2014 as seen in the Figure 51. Combining these effects, the integrated operator selecting the non-FMC path is foreseen to be in a much weaker position in the end of the period, in this kind of competitive situation. According to Figure 51, the yearly net cash flow increase derived from the FMC scenario sum up to over 2 B€ in the end, endangering the long-term survival of the non-FMC integrated operator.

Nowadays an incumbent integrated operator faces the challenges of growing competition by new entrants in the form of (Internet) service providers and meanwhile well established mobile operators with lower operational costs and generally higher flexibility to market dynamics. Only together with the use of common interoperable standards for both the fixed and mobile networks and their integration, at least at the level of common service provisioning platforms (application plane) to simplify deployment of intuitively usable converged services, and with unified marketing (single bill), will the customer attractiveness and OPEX savings increase, fostering the profitability of the integrated operator in the long run.

4.4.4 Assessment of the convergence case analysis

Investigation of the cost structure of the integrated fixed-mobile operator, combined with the new technological and marker possibilities and challenges led to suggestion for a rather aggressive convergence strategy for the incumbents. The approach is a challenge for the operators, as it is not mainly a technological development step, but a strategic market approach and organisational change process.

As the measures taken towards the FMC and the related benefits are difficult to count outside the company itself, it is challenging to make definite conclusions about the accuracy of the presented estimates. Although there has been plenty of supply from the equipment vendors and most Western-European integrated operators have even had IMS trials stating from 2005 (e.g. TIM in Italy and TeliaSonera in Nordic countries), for most part of the industry the implementation of full fixed-mobile convergence has been delayed. Therefore, the accurate correctness of the suggestions for the profitability of the convergence will be revealed only in the future.

The development in mobile technologies has been fast in recent years, however, so that a market disruption, where the mobile broadband through HSDPA is challenging the fixed DSL access, is at hand. For example, in Finland the number of DSL accesses started to decline in 2008, as customers migrated to mobile broadband, which reached a 30% share of all BB accesses in mid 2009 (FICORA 2009). This is not yet what is meant with seamless service convergence, but one indication that through technology development the clear-cut separation between fixed and mobile access is vanishing, and the organisations and business architectures have to adopt.

In recent times many restructuring efforts have in fact been launched. In 2006, France Telecom rebranded its ISP operations (previously Wanadoo) under its mobile brand Orange and started to provide both mobile and fixed IP services together in various packages. The ordinary fixed telephony was still left as separated unit. The pressure towards restructuring has been high in France, causing friction and problems among the personnel in a long history incumbent with state owned background as France Telecom. Full integration of the fixed and mobile networks and services is still to be implemented, but IMS pilots for mobile multimedia services have started in 2009, and even interoperability tests between the major French mobile operators Orange, Bouygues Telecom and SFR.

Although continuous development efforts and trials, other Western-European markets have been lagging behind. In most cases the fixed and mobile arms of the operators are still in their own organisations, and even competing against each other in certain services like in the case of mobile broadband (HSDPA) and DSL access. But Deutsche Telekom has announced that it will start merging its fixed and mobile divisions in Germany in the first quarter of 2010 using the One Company concept, as the extraordinary shareholders' meeting on 19 November 2009 approved the plan (Deutsche Telekom AG 2009). The designated CEO of the DT German operations has commented that T-Home's and T-Mobile's service and sales departments have already before that been 80 percent integrated and the marketing, technology and products will follow suit (Telecompaper 2009).

This development confirms that despite the hard implementation task, the benefits, modelled in the techno-economic delta analysis of Publication 6, are so remarkable that the restructuring and fixed-mobile service alignment is inevitable and taking place. As noted in relation to the earlier case studies, realisation of the new, mainly Internet based, technologies and services require completely new business architecture and co-operation between the development forces in the market. Old organisational and technology-related constraints need to be removed to be competitive in the new communications business. This development, although started in one form or another inside most operators, is a gradual long-haul endeavour, as requiring, in addition to the network and terminal changes, in the end, unification of all the front-end and back-end operational and business support systems and processes.

5. SUMMARY AND CONCLUSIONS

The research question in this thesis was how to develop the techno-economic methods for valuation of advanced mobile communications business prospects and demonstrate that the elaborated quantitative models

- can successfully predict the profitability of the investigated cases
- are useful in technology and business architecture comparisons
- help the stakeholders in finding the optimal technology strategy.

This question was approached within three technology frameworks: UMTS/WLAN, UMTS/WiMAX and fixed/mobile convergence through UMTS IMS. In each technology study, in addition to scenario valuations, some steps were taken to develop the techno-economic method, as well as in the separate study on real options application.

UMTS/WLAN profitability

The study started with a UMTS deployment case based on a strategy to invest in provisioning of a wide range of advanced services utilising high data traffic capacity, and this way to increase the revenue per user. In this case study, the techno-economic model was much relying on a future looking classification of advanced mobile services including demand and revenue potential estimation, as well as related traffic and cost modelling.

Looking at the actual market behaviour afterwards, it can be found out that the major Western-European incumbents were hesitant to invest in the rapid UMTS service development and rollout in the beginning of this century, as the ICT downturn led to major cost cuts. Most of them were also in deep debts, and they wanted to postpone the large UMTS investments. In spite of this, the UMTS diffusion developed in many Western European countries according to the study suggestions, but in some countries like UK, Germany and especially France the diffusion has been considerably slower.

The small investments in service development set some challenges on the evaluation of the revenue modelling. There was, however, a clear exception to the prevalent attitude to wait: Hutchison 3G group, which offered 3G services in the UK, Italy, Ireland, Austria, Denmark, Sweden and Australia, and was investing heavily in the UMTS networks, as well as all categories of advanced services, starting almost immediately after the European UMTS auctions in the year 2000. H3G group was not a 2G incumbent, but a challenger with no own 2G network, so that the special case study for the challenger matches this case.

The challenger business case was more demanding than the incumbent case, as it had to start network building from scratch, owning not even antenna sites, and needing to rent the 2G GSM and GPRS capacity for roaming in those areas that they had not yet covered with their UMTS network. An even greater economic burden was that they had to start growing their customer base from nil, with average customer acquisition cost per new customer as much as 293USD in 2005 (Lion 2007). For these reasons the profitability figures calculated for the incumbent actor were not applicable as such, but the revenue side is basically the same and could be used for comparison and verification of our estimates also in the incumbent case.

As presented in the assessment of the UMTS/WLAN case in Section 4.1, the average revenue per user (ARPU) that the H3G Group generated from their service provisioning was in line with the case model until the year 2006. From 2007 onwards, the revenue growth started to decline under the pressure of the price competition by the incumbents and the payback period was prolonged from what was predicted. As a conclusion it is possible to state that the revenue potential from UMTS services was there from the beginning of the study period, as the study proposes.

The profitability prediction for the incumbent case could not be directly validated as the incumbents did not make the investments in accordance with the modelled schedule. However, indirectly it can be seen from the results, that with the predicted revenue structure (that realised in the H3G Group case) and the lighter cost structure of the incumbent operator, the business would have been profitable already in 2006.

If the incumbent UMTS operators would have invested heavily in the 3G rollout and service development, instead of choosing the price competition with low investments, they could have been able to change the general spending to communications services not to bend down and start to decline in the 2000's. Even though a definite statement concerning the past cannot be given, further development in the field will reveal if there is still high latent potential in the mobile services to be released through new business architectures, products and services. It is not only a question about technology development, but about how to build business incentives and channels to feed fertile co-operation, usage scenarios and services. All the actors in the converging communications and media value network need to get a fair share in building the flourishing mobile services ecosystem.

The other main research topic was the economic impact of the public WLAN provisioning. The developed techno-economic model clearly indicated that WLAN will not become a serious challenger to the incumbent's mobile data provisioning that takes place through UMTS technology path. It will rather become a possible supplement for the ubiquitous mobile networks to serve some special areas like airports, and the related impact will be minor in the whole of the operator business and its profitability. These results were based on both revenue and cost modelling of the relevant business actors and have proven to reflect what actually took place. After the geographical spreading of the HSDPA technology, the significance of the public WLAN solutions has even decreased. It should be noted that only the public WLAN business is referred here, as the private usage in homes and business premises is extensive. The public WLAN business had problems in providing ease of use through ubiquitous single sign-on access and payment methods.

UMTS/WiMAX comparison

The next studies were begun in the situation, where UMTS had already started to be deployed in Western Europe. But as the UMTS was rolled out on a larger scale in the Western Europe, in some cases several years behind the original schedule, newer, fully IP based technologies were already rising. OFDM based technologies were argued to be much more cost efficient, UMTS being already an obsolete technology. Investing in UMTS should be reconsidered, and leapfrogging directly to a more advanced technology generation to be weighed instead.

A little later, the mobile WiMAX technology was winning the competition to be the number one challenger technology. Against this background, the goal of the study was to analyse the technology competition between those two, and provide guidance for the business actors in their strategic selection of the most profitable technology path. Also the intermediate technologies, like EDGE, had to be taken into account in this modelling, as it is not a question of isolated technology solutions, but a continuum of path dependent provisioning, where several technologies are overlapping to serve different use cases - depending on user, service and geographic area type. Thus the totality of the services through several technologies should be modelled.

The technology comparison related to provisioning of these services requires also means to model the differences in user experience provided by the technologies and the induced usage and thus revenue. Tools to analyse the complete end-to-end value chain of the services was enhanced by separating the network and service provisioning models and integrating the end-user experience effect into the techno-economic modelling.

Techno-economic analysis taking into account the network capacities and cost structures, as well as devices and end-user characteristics of the available technologies, led to the conclusion that the UMTS path would provide clearly better results both for the Service operator and for the Network operator. This basic result indicates that mobile WiMAX would not have a strong position at least in the Western European context during the first decade. The major operators will generate the highest revenues and best profit through an EDGE/UMTS/HSPA combination with continuing path to LTE, and will, therefore, select that route. It was predicted that the weaker position in technology maturity and device mass-market, combined with cost efficiency that will be not much superior to the UMTS enhanced with HSPA, will not give good prospects for mobile WiMAX among the big actors.

This forecast has come true in the market, as the few mobile WiMAX deployments until 2009 have been very modest compared to the UMTS in Western Europe and throughout the world[1]. This view was, however, arguable when the studies were performed. Too narrow a view concentrating only on technology or an individual service can easily lead to overestimations that should be avoided through comprehensive techno-economic modelling.

Improvement of valuation through real options application

In the techno-economic research relating to future technologies, the market development is largely unknown in the beginning - even more so than the technology parameters themselves. Therefore the thesis studies have utilised versatile methods to describe the risk and sensitivity upon the baseline results and also developed further the techno-economic valuation of communications infrastructure investment projects by applying the real options method in some of the case studies.

Although there is often the possibility to make some of the investment decisions later, valuable incomes and the first mover advantage are easily lost by postponement in case of network rollout related projects where the infrastructure construction requires considerable time before the revenues can be reaped. The decision has to be made early enough with more fuzzy information. This pattern differs from the nature of the stock options, which can be exercised at certain point (or any point) of time and the market value is cashed immediately.

However, as the rollout takes time and is not feasible to perform simultaneously everywhere (and not even possible in practice), there is room to fine-tune the schedule of the later part of the deployment plan. Even the technology combination could be changed for that part. This flexibility has a value that can be calculated soundly with the real option method, if the volatility of the project value that depends on the market development can be modelled adequately.

[1] Note: **fixed wireless** WiMAX deployments are not discussed here.

As the cashing period of this kind of technology projects always shortens when postponed, the losses are greater than the benefits from waiting for new market information in many cases. In cases where it is optimal to build immediately, the real options calculation does not change the results from the ordinary DCF modelling. This is the case where the expected benefits from waiting are less than the respective estimated losses of revenues. But especially in cases where some investments have to wait in any case, the real options can provide more proper valuation of the project, as market conditions may change so that another kind of technology deployment may become optimal.

The results show that in the investigated mobile technology deployment cases the flexibility does not bring remarkable differences to the results. UMTS rollout is clearly justified in the decision point, even if the market development happens to go in the negative direction. But for remote area rollout the flexibility is demonstrated to have indisputable value that should be taken into account in the calculations to get the most precise key figures for the technology project. So technology decisions for remote areas should not be made beforehand, but to look at the market development and make the decision later, when needed. Real options calculation provides the sound method to calculate the project value in this kind of cases. In the representation of real options analysis it was aimed for maximum concreteness of the reasoning so that its impact and justification would be as comprehensible as possible for practitioners.

Convergence scenario valuation

Lastly, the research focuses on the profitability of the fixed-mobile convergence for the integrated operators, who own both fixed and mobile networks together with service provisioning. It is considered as a natural continuum for the UMTS path and its IP Mobility System (IMS) deployment. The same kind of technological migration to all IP as the IMS in the mobile network side is taking place in the fixed network side under the NGN (Next Generation Networks) concept. However, the scope is not only the technical development, but rather the wider business perspective, where the product and service offerings and the organisation of the operations proves to have an even higher impact than the technical implementation.

Delta analysis is used to track the benefits and increased revenues against the losses and costs in this business transformation. The results indicate that an integrated operator can achieve additional profits through better customer retention, as it can tie up high value customers by its competitive convergent service packages. Also new value adding services that are enabled through the convergent environment will increase the profitability and operating costs will reduce clearly after the initial transformation phase.

The needed investments in the network development and servers for fixed-mobile convergence are minor compared to the savings and added revenues mentioned above. The most important negative factor identified was the revenue reduction from certain customers due to convergent service packaging - to provide lucrative packages requires discounts for the customers. But the positive side is in luring new customers and retaining the old ones through comprehensive service provisioning that locks the customers effectively. That is estimated to clearly surpass the negative effect and increase the business value substantially. Further investigation is required though to assess the impact of new integrated network and service platforms on the overall system performance, QoS, security, scalability and the potential for easy and fast deployment of new services (service modelling), including the converging front office and back office IT systems of the operator.

Fixed-mobile convergence has advanced slowly, although technical solutions for the converged networks through IMS have been developed intensively already a decade. Surely there are challenges to integrate a large and versatile set of current and evolving future equipment together. In the network part it is moderate task to control the interoperability of the elements, but on the device side the management of all the possible configurations is demanding. The vast majority of the mobile devices have been utilised in the past only for a simple set of services, but as the spectrum of services and device functionality increases, the management of the interfaces in the field becomes more challenging.

But as the demarcation to fixed and mobile technologies is vanishing, the most challenging part in the convergence is the organisational and procedural transformation relating to the new business structures. These changes are concentrated on in the study in addition to the technical prerequisites. The efficient convergence requires a single organisation and unified business processes for managing the service portfolio as a whole - the network technology through which the service is delivered in different use cases being secondary. Notwithstanding some development efforts towards FMC and IMS implementation and organisational changes by many of the integrated operators in recent years, for most operators some fixed network solutions and mobile solutions still practically compete against each other as the revenues from each go to different accounts. This easily affects the view to the service choice provided to the customer and thus the usage patterns and service experience. If the marketing and provisioning are not unified, revenues are lost and costs will be higher in the long run according to our study. The measures to migrate to a unified organisation are demanding, as each part of the organisation naturally wants to keep its dominance.

Changes in the technology and market competition have already triggered the decisions of major market actors to accelerate the integration and convergent service development, and the benefits from convergence that were quantified in the study are not denied. But as with the UMTS case, new technologies and services risks the telecommunications operators' older and simpler revenue streams that are based in most cases on major investments, and as long as they are providing good profit, the actors have an inherent inertia to making these massive investments and changes. This relates also to the fact that in the current communications markets it is difficult to enlarge the business through innovations, as the customer base has saturated and has a restricted or even declining budget on communications (OECD 2009)[2] and even the service concepts are in many cases rather easy to copy by the established competitors.

Final conclusion

The assessment of the results from the presented studies indicate that the techno-economic method can be successfully applied to quantitatively valuate and compare different advanced mobile technology scenarios through comprehensive modelling that combines technology, business and service experience aspects. As a workable model has to reflect the investigated business actors' strategic choices and the competitive business architecture developments, the possible case variants are endless. But even if the analysed cases do not completely match a particular actor's case, the results would give valuable guidelines for the strategic decision making in the challenging business environment.

[2] The proportion of household spending to communications switched to a decreasing trend after the year 2004.

6. FURTHER STUDY

In this research work, the 3G technology deployment for provisioning advanced services was first modelled starting from analysis, classification and diffusion forecasts for the foreseen new services, together with the mobile technology evolution tracking. The infrastructure construction and service provisioning costs and revenues were then estimated based on that. The approach concentrated on incumbent mobile operators, who had the strongest position in providing the services, although the other actors like MVNOs and challenger operators were analysed beside them, as complementing actors. In the later studies, the service provider model was separated from the network provisioning to gain more visibility on the business, and the end-user model was introduced to better analyse the effect of the end-to-end service experience. Business structure and related operational costs analysis was developed further and real options approach integrated into the modelling to improve the scope and accuracy of the studies.

Modelling the new competitive environment

It has become clear, however, that these efforts have not been sufficient to cover the value creation processes and technology competition in the new converging ICT and media economy. Further technology investigations are required to assess, in addition to the increasing radio capacity, the impact of new integrated network and service platforms, including the converging front office and back office IT systems, on the overall performance, QoS, security, scalability and the potential for easy and fast deployment of new services. This evolution is foreseen to enable new service provisioning approaches, business architectures and partnering schemes.

As the services became more integrated through complicated technology and business architectures, and the usage scenarios harder to predict, the operators were found not to be prepared to master the whole ecosystem. This is not surprising, if considered that before the rise of the first IP data services in the latter part of the 1990's the complexity was almost fully in the network, and the devices and services were only the standardised ones. In the new economy the old simple value chain, where the operator solely owned the end-user has turned to a complex network of relationships and the Internet has brought many actors into direct connection with the customer.

Also mobile equipment vendors want to broaden their scope of business to include the services, as the competition is more and more between end-to-end solutions and the related user experience. In the iPhone case, for example, the control of the value network, applications and services has shifted much from the operators to the equipment vendor that supports the application development and service provisioning through Internet. From the other side, the Internet companies like Google broaden their scope towards the equipment end of the value creation. The actor in the business architecture that owns the winning product IPRs can control the value network, establish the best partnerships and make the best profits. The value of owning the network infrastructure and customer base has diminished, and creativity with the ability to anticipate and learn the user needs and future usage scenarios, together with winning their trust, has increased in impact. In the Internet service market, the individual margins are so thin that revenue share between many layers is not feasible. It is a competition based on as wide international customer access as possible, and the advertisers are becoming a major revenue stream for the service providers. Two sided revenue streams are emerging in the operator business, where product promoters on one side and end-users on the other side are brought together.

For these reasons, the valuation of the business prospects in the context of advanced mobile technologies and services requires quantitative modelling of more actors in the identified ICT and media business architecture. The modelling should cover complete scenarios, where all actors forming the value network have a feasible business case. The current research ended up in separate but interlinked models for three actors (network provider, service provider and end-user), where especially the service provider had multiple roles, but more business actors should be modelled separately to be able to fully describe the potential advanced ecosystem revenue streams and their dynamics.

No techno-economic modelling can, however, solve for certain the best solution in situations where there is much room for new innovations in the business. Its nature is more of a tool that can be used to demonstrate the relative strengths of the foreseen alternatives. But if there are dimensions that are not perceived in the modelling or scenario creation, and those factors or actors will prove to be crucial in the realised business, the techno-economic model cannot help much. Avoiding of these limitations depends on the intuitive vision in generating an extensive set of scenarios from the observed technology and market development, but future looking analysis of the technology and business architectures and projections between them would supply a good tool to help in this too.

As the competition is taking new forms in the ICT and media business, the analysis of an actor's own competitive position in relation to the future business architectures will be crucial in estimating the revenue potentials. Future study could also apply dynamic modelling, based on, for example, game theory or system dynamics, instead of scenarios having pre-defined strategies for the actors. The challenge is again to generate all the relevant actors, strategies and business architectures that would develop in the future, an additional challenge being in modelling the competition between the different solutions. If we include end-users among the business actors, dynamic modelling of the whole becomes easily too complicated and it may be more practical to try to model the market changes as stochastic changes in defined model parameters, as done in the simulations when the real options modelling was applied.

Decision making dynamics through real options

One possible view on the dynamics of the future decisions is through the real options application that brings in a broad field for further study too. Real options were first introduced in industries like oil drilling, where the oil price acts much like stock prices in the stock market. The postponement of a project may lead in better output as the price probably rises in the long run and if the oil is not drilled up its value even under the ground will rise. Within industries like ITC, the situation is much more complex. If a technology is not deployed early enough, it may lose its value totally, as an alternative may conquer the market. If a company does not deploy an innovation, it may be utilised by a competitor, taking the market advantage and ruling the slower company out. A technology has usually also a time window, so that if it is taken into use later, the cashing period would be shorter. In communications the larger network deployment and higher capacity usually leads to growing revenues, boosted by the growing network externalities, but the wide rollout requires time so that any lag in the start may cause high revenue losses in the longer run.

On the other hand, if a service innovation, not requiring a long learning period, has not yet reached the breakthrough point in its diffusion, the investments may give a low return in the beginning and the competitor may come into the market when the time is more optimal. The price of the purchased technology can also reduce, but the capability/capacity increase, substantially after the initial phase.

Thus it should not be assumed that the deployment project value would be the same not depending on whether the project is launched following the original schedule or postponed, but on the contrary, if the project is postponed, the delay should affect all of the model parameters that are time dependent. The above factors are considered in the design of the models and taken into account in the real option calculations of the thesis, but far more dynamics can be introduced to the treatment. For example, the presented lattice was constructed with the granularity of one year, but shorter time steps could be introduced, requiring that the whole modelling should be done with, for example, quarterly parameter estimates. The service usage parameter was used in modelling the volatility in market demand, but the market uncertainty could be modelled in a more diverse way, estimating, for instance, the demand together with the price development. If the demand grows well, the competition would probably drive the prices downwards. The volatility could also change as the time passes, according to the model dynamics.

The diffusion patterns could also have completely different shapes in the postponed market entry situations than in the original schedule case. The evolution of the competitive situation and different business architectures could be taken into account as analysing the diffusion for the analysed business actor in the postponement alternatives. Also growth options related to certain technology deployment paths and business architectures could be integrated into the calculations. In the decision points, not only the technology could be switched, but even the business architecture could be modified, if certain market conditions appear. All in all, there are many opportunities and challenges in introducing the market volatilities realistically into the real option models for communications business actors, together with choosing the right alternatives of the flexible deployment plan. Through the development work, real option analysis could become a practical and established part of the valuation of different business actors' scenarios in the new communications and media industry ecosystem.

7. AUTHOR'S CONTRIBUTIONS TO THE PUBLICATIONS

Publication 1: Harno, J. (2004b). 3G Business Prospects - Analysis of Western European UMTS Markets. Proc. 1st International Symposium on Wireless Communication Systems (ISWCS). Mauritius, September 20-22, 5 pages.

The article has been written by the thesis author, based on the design and modelling of the UMTS study in the TONIC project, in which work the author has been the main single contributor.

Publication 2: Olsen, B. T., Katsianis, D., Dimitris D., Stordahl, K., Harno, J., Elnegaard, N. K., Welling, I., Loizillon, F., Monath T., Cadro P. (2006). Technoeconomic Evaluation of the Major Telecommunication Investment Options for European Players. *IEEE Network*, Vol. 20, no. 4, July/August, pp. 6-15.

The author has written most of the UMTS-WLAN part (pp. 9-12) of the article, which is based on the modelling work where the author was the main contributor. He has also contributed to the mobile forecasting part and the modelling of the MVNO part in the paper.

Publication 3: Harno, J. (2009a). Techno-Economic Analysis of Beyond 3G Mobile Technology Alternatives. *info, Emerald Group Publishing,* Volume 11, Issue 3, pp. 45-63.

The author has designed the case study setting in relation to the ECOSYS project, constructed the Service operator and Network operator models and written the article.

Publication 4: Harno, J., Katsianis, D., Smura, T., Eskedal, T., Venturin, R., Pohjola, O-P., Kumar, K. R. R., Varoutas, D. (2009a). Alternatives for mobile operators in the competitive 3G and beyond business. *Telecommunication Systems,* Volume 41, Issue2, pp. 77-95.

The author has compiled and edited the article, writing the introduction and conclusions, was the main contributor to the Scenario 1 part and contributed to the others.

Publication 5: Harno, J., Bedo, J-S., Katsianis, D. (2005b). Analysis of 3G mobile technology rollout alternatives using real options methodology. Proc. NAEC2005, Italy, Oct 2005, 15 pages.

The author designed and modelled the baseline case study and the binomial lattice ROA application upon it.

Publication 6: Harno, J., Kumar, K.R.R., Heikkinen, M., Kind, M., Monath, T., Von Hugo, D. (2009b). Service Offerings for Fixed-Mobile Convergence Scenario: An Integrated Operator Case. *International Journal of Business Data Communications and Networking (IJBDCN),* Volume 5, Issue 3, pp. 1-16.

The author was one of the main contributors to the scenario design and modelling and the editor of the article.

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